9.3.4 Chemical and Volume Control System (Including Boron Recovery System)

The chemical and volume control system (CVCS) interfaces between the high pressure (HP) reactor coolant system (RCS) and low pressure (LP) systems in the Nuclear Auxiliary Building (NAB) and Fuel Building (FB). The CVCS is divided into the following three major sections:

- Letdown.
- Charging.
- Reactor coolant pump (RCP) seal water.

9.3.4.1 Design Bases

The CVCS performs the following safety-related functions:

- Maintain integrity of reactor coolant pressure boundary (RCPB) in the event of a CVCS letdown line break downstream of the RCS through closure of redundant motor-operated isolation valves. Redundant check valves in the charging line and pressurizer auxiliary spray line provide RCPB integrity.
- Mitigate boron dilution event by automatically isolating the charging pump suction from the volume control tank (VCT) and normal letdown path.
- Provide automatic isolation of charging and auxiliary spray line to prevent pressurizer over-fill in the event of a CVCS malfunction.
- Provide containment isolation by automatic closure of charging and letdown lines and RCP seal water injection and return lines.

The CVCS has the following design basis requirements and criteria:

- Safety-related portions of the CVCS are designed, fabricated, erected and tested to quality standards commensurate with the importance of the safety functions to be performed (GDC 1).
- Safety-related portions of the CVCS are designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami and seiches without loss of capability to perform their safety functions (GDC 2).
- Safety-related portions of the CVCS are not shared among nuclear power units (GDC 5).
- Safety-related portions of the CVCS are designed to maintain RCPB material integrity by means of the CVCS being capable of maintaining RCS water chemistry necessary to meet pressurized water reactor (PWR) RCS water chemistry specifications (GDC 14).

- Safety-related portions of the CVCS are designed to reliably provide negative reactivity to the reactor by supplying borated water to the RCS in the event of anticipated operational occurrences (AOO); if the plant design relies on the CVCS to perform the safety function of boration for mitigation of design basis events (DBE) (GDC 29).

- Safety-related portions of the CVCS are designed to supply reactor coolant makeup in the event of small breaks or leaks in the RCPB and to function as part of the emergency core cooling system (ECCS) assuming a single active failure coincident with a loss of offsite power (LOOP); if the plant design relies on the CVCS to perform the safety function of safety injection as part of the ECCS (GDC 33 and GDC 35). CVCS valves are designed to fail to a position (i.e., closed, open, or as-is) upon loss of motive power that meets safety analysis assumptions.

- Safety-related portions of the CVCS are designed to have provisions for venting and draining through closed systems (GDC 60 and GDC 61).

- Safety-related portions of the CVCS are designed to have provisions for a leakage detection and control program to minimize the leakage from those portions of the CVCS outside of the containment that contain or may contain radioactive material following an accident (10 CFR 50.34(f)(2)(xxvi)).

- Safety-related portions of the CVCS are designed to provide sufficient capacity and capability to make sure that the core is cooled in the event of a station blackout (SBO) (10 CFR 50.63(a)(2)).

The CVCS is designed to meet the following functional criteria:

- Maintain and adjust the RCS boron concentration to control reactor power level variations resulting from expected reactivity changes due to the effects of xenon build-in or burn-out, and compensate for core burn-up to provide assurance that operating fuel limits are not exceeded.

- Maintain RCS water inventory by maintaining a constant charging flow and adjusting the letdown flow to account for volume changes due to RCS temperature variations.

- Provide cooled, purified and filtered water to the RCP seal water system to maintain cooling and leak tightness of the RCP seals and return seal leakage back to the CVCS.

- Provide cooled reactor coolant for chemical and radiological control of the primary coolant in combination with the coolant purification, treatment, degasification and storage systems.

- Add chemicals to the RCS to control the pH of the reactor coolant during all modes of operation; also add hydrogen to the RCS to counteract the production of oxygen in the reactor coolant due to the radiolysis of water in the reactor core region.

- Provide an auxiliary spray line to the pressurizer to control reactor coolant pressure in the event the normal spray cannot or is not sufficient to provide the spray function, or when a decrease in RCS pressure is required during cooldown operations.

9.3.4.2 System Description

9.3.4.2.1 General Description

The CVCS provides a flow path for the continuous letdown and charging of RCS coolant. It maintains the RCS water inventory at the desired level via the pressurizer level control system and provides RCP seal water injection and auxiliary spray for pressurizer cooldown. A flow diagram of the CVCS is shown in Figure 9.3.4-1—Chemical and Volume Control System.

The CVCS is normally in continuous operation during all modes of plant operation from power operation to cold shutdown. It is not required for the mitigation of any design basis accidents (DBA). However, the CVCS can be utilized to preclude the use of safety systems during minor plant transients (e.g., boron dilution events). The safety-related components of the CVCS are redundant and no single failure compromises the safety functions. All vital power can be supplied from either onsite or offsite power systems as described in Chapter 8.

Charging, Letdown, and Seal Water

Water from RCS Loop 1 crossover leg (between steam generator and RCP) enters the letdown portion of the system and exits the RCS through two motor-operated isolation valves in series. The flow then passes through the tube side of the regenerative heat exchanger, transferring heat to the charging flow returning to the RCS on the shell side. The HP cooler, which is cooled by the component cooling water system (CCWS), further cools the letdown flow to approximately 120°F, then pressure reduction valves depressurize the letdown flow. The pressurizer level control system automatically controls the letdown flow through the pressure reduction valve. Downstream of the pressure reduction valves, a relief valve provides overpressure protection of the letdown piping inside the Reactor Building (RB). A bypass connection allows discharging letdown flow to the reactor coolant drain tank (RCDT) and into the IRWST. This connection permits letdown from the RCS if a portion of the CVCS or equipment outside containment is not available.

The letdown flow then passes from the RB into the FB through two containment isolation valves (CIV). A pressure control valve downstream of the CIVs maintains the upstream pressure at approximately 75 psig. Maintaining this constant pressure creates less wear on the pressure reducing valve internals. The letdown flow is sampled and purified in the FB. During normal power operation, the purification flow rate is sufficient to treat at least one RCS volume in 12 hours.

If required by radiochemical analysis, the coolant degasification system (CDS) degasifies the letdown flow. A major portion of the letdown flow is then directed to the hydrogenation station, which mixes hydrogen gas into the flow stream to scavenge oxygen resulting from the radiolysis of reactor coolant. A small portion of the letdown flow, approximately ten percent, is directed to the VCT to maintain the boron concentration in the tank in chemical equilibrium with the RCS. The VCT acts as a surge tank to permit smooth control of variations in charging and letdown flow rates. Provisions allow the diversion of any excess letdown flow to the coolant supply and storage system (CSSS) because of the volume expansion of the RCS resulting from system heatup or from any required boration or dilution. Connections to the CVCS allow chemical additions and boric acid and demineralized water makeup.

The charging pumps take suction from the letdown line and VCT and increase the pressure to allow purified coolant to be returned to the RCS. In the event of a VCT low level or if a dilution incident is detected, the charging pumps take suction from the IRWST. If either condition is detected, a motor-operated valve (MOV) from the IRWST automatically opens and the MOVs from the VCT and letdown line automatically close.

The main charging pump discharge flow passes through the shell side of the regenerative heat exchanger, which increases the temperature of the flow prior to injection into the cold legs of RCS Loops 2 and 4. A motor-operated control valve adjusts the charging flow rate to maintain a constant charging flow.

A portion of the charging flow is delivered to the RCPs for shaft seal water. The seal water is filtered and motor-operated control valves to each RCP automatically control the flow of seal water during plant conditions when seal injection is required for RCP operation. The number one seal leakoff flow discharges to a common header and passes through the return filter to the VCT to maintain CVCS inventory.

A three-way, MOV downstream of the regenerative heat exchanger aligns the CVCS charging flow to the pressurizer auxiliary spray nozzle to reduce RCS pressure to reach safety injection system (SIS) and residual heat removal system (RHRS) conditions.

An LP reducing station allows the RHRS to utilize the letdown flow path and the coolant purification system (CPS) during shutdown conditions when the RHRS is in operation.

Even though the CVCS is not required to perform any DBA mitigation functions and is only an operational system, emergency buses, backed by the emergency diesel generators (EDG), power the CVCS MOVs. The CVCS charging pumps are provided backup power from the Station Blackout (SBO) diesel generators.

The major components of the CVCS are located in the RB and FB. The building design protects these components from external hazards and the components are either physically separated or provided with protection from internal hazards. To prevent precipitation of boric acid, CVCS components and piping containing boric acid are located within heated rooms.

Coolant Purification System

The CPS provides continuous full CVCS letdown flow purification. The CPS comprises three inlet filters, two mixed-bed ion exchangers and two outlet filters. If the letdown temperature is less than 140°F, a three-way valve in the CVCS letdown line directs reactor coolant to the system inlet. If the letdown temperature is greater than 140°F, the three-way valve automatically closes and bypasses the purification system. A flow diagram of the CPS is shown in Figure 9.3.4-2—Coolant Purification System.

During normal operation, the reactor coolant passes from the CVCS letdown line three-way valve through two inlet filters in parallel, one mixed bed ion exchanger and two outlet filters, before returning to the CVCS letdown line downstream of the three-way valve. The inlet filters are cartridges that filter undissolved corrosion products to prevent them from entering the resin beds. The outlet filters operate in parallel and act as resin traps to prevent resin carry over into the CVCS and connecting systems. The CPS allows purification of the maximum CVCS letdown flow during plant operation.

The CPS is manually operated. The main control room (MCR) provides indications of the differential pressures across the mixed bed ion exchangers and cartridge filters. If a high differential pressure is sensed, the three-way inlet valve is closed and bypasses the system.

Both ion exchangers are initially charged with the same quantity of resin, one in the form of Li+ and OH^-, and the other in the form of H^+ and OH^-. Both are saturated with and boron. The lithium form ion exchanger serves as the main purification ion exchanger. The other ion exchanger removes cesium and excess lithium produced in the RCS.

The main purification ion exchanger and the lithium and cesium removal ion exchanger operate alternately. When the upper specified lithium limit is reached, the purification flow is switched to the lithium and cesium removal ion exchanger until the lithium concentration is lowered to an acceptable level.

When the main purification ion exchanger is exhausted or if the differential pressure across the ion exchanger bed reaches an established value, the ion exchanger is isolated. Then the lithium and cesium removal ion exchanger is saturated with lithium by the addition of lithium hydroxide into the CVCS and RCS. When the ion exchanger is saturated with lithium, it serves as the main purification ion exchanger and the resin of the former main purification ion exchanger is changed. After resin replacement, the former main purification ion exchanger serves as the new lithium and cesium removal ion exchanger.

During plant shutdown conditions, the RHR pumps provide the motive force to allow purification of the reactor coolant. A branch line from the RHR pump discharge passes reactor coolant through the CVCS LP reducing station to the letdown line. Flow passes to the purification system, and then the return flow bypasses the VCT and charging pumps and enters the charging pump discharge line to the RCS.

Coolant Degasification System

The CDS removes radioactive gasses as well as oxygen and hydrogen from the RCS. The system accepts the full CVCS letdown flow via a three-way valve in the letdown line. The letdown flows into the degasifier column, which degasses the flow and returns it to the letdown line downstream of the three-way valve. The CDS operates as a vacuum degasifier at a pressure of 1.693 psia. This corresponds to a boiling temperature of approximately 120°F, which is the CVCS letdown temperature.

Since continuous degasification of the reactor coolant is not necessary, the system is normally in a standby condition. A flow diagram of the CDS is shown in Figure 9.3.4-3—Coolant Degasification System. During power operation, the system is placed in operation to reduce the concentration of noble and other gasses as determined by chemistry analysis.

The system operates prior to refueling or if repair work requires the opening of any component that contains reactor coolant. This removes hydrogen and any radioactive gasses from the reactor coolant to minimize the release of radioactivity to the atmosphere when the RCPB is opened.

During outages when the RCS is opened, air from the atmosphere dissolves in the reactor coolant. The degasification system operates during and after these outages to remove the dissolved gasses and prevent the corrosive attack to the pressure retaining boundary materials of the RCS.

Reactor Coolant Chemistry Control

During normal operation at operating temperatures, the RCS pH is maintained in the alkaline range. This minimizes the corrosion of materials exposed to reactor coolant, minimizes the deposition of corrosion and wear products on fuel and plant surfaces, and reduces the susceptibility of structural materials exposed to reactor coolant from stress corrosion cracking. Lithium hydroxide is added into the coolant to maintain the pH value in the alkaline range. The use of the isotope Lithium-7 is specified for radiological reasons. Periodic analysis of the coolant determines the amount required for the injection.

During normal power operation, the Boron-10 (n,) reaction produces Lithium-7. The coolant purification ion exchanger that is not saturated with lithium removes excess lithium. The addition of Lithium-7 may be required if there is a high RCS makeup requirement.

If lithium addition is required, the lithium hydroxide solution is mixed in the lithium hydroxide preparation tank by a manual agitator to provide a homogeneous solution. Then, the entire mixed quantity is transferred into the lithium hydroxide injection tank where the chemical addition pump injects the required amount of solution into the CVCS charging pump suction.

The oxygen in the RCS is controlled by the addition of hydrazine at low temperatures and maintaining an excess of hydrogen during power operation.

The mobile hydrazine injection system supplies the required amount of hydrazine to a chemical proportioning pump. The chemical proportioning pump discharges the hydrazine to the CVCS charging pump suction.

The hydrogenation station located in the charging pump suction line adds hydrogen to the RCS. The concentration of hydrogen in the reactor coolant depends on the hydrogen partial pressure in the gassing unit. The pressure in the VCT maintains the pressure in the gassing unit. The VCT pressure is adjusted so that it corresponds to the saturation pressure for the required hydrogen concentration in the reactor coolant. The pressure control of the nitrogen purging gas maintains the VCT pressure at a constant value even during level variations in the VCT.

Since nitrogen from the VCT will slowly accumulate in the gassing unit, pressure by itself cannot be used to determine the hydrogen concentration in the RCS. The CVCS is equipped with two independent methods for measuring hydrogen concentration in the coolant. The first method uses an online hydrogen monitor that operates on the principle of thermal conductivity and provides real-time data to plant operators for the control of coolant hydrogen concentration. The second method uses an analysis of a stripped gas sample to determine the dissolved hydrogen concentration. Both the online analyzer and grab sample are taken from a letdown sample point upstream of the coolant purification and hydrogenation systems.

During the startup of the gassing unit, hydrogen is not admitted until the gas separator reaches its operating level. At that time, the water jet pump, which exhausts gas from the gas separator and injects it into the mixing element, is placed into operation. A branch line from the charging pump discharge line supplies the propellant liquid for the water jet pump. After the gas separator reaches its operating water level, the gas distribution system injects hydrogen into the gas separator. The gassing unit contains connections for adding hydrogen and for venting and flushing with nitrogen.

If the hydrogen forms larger gas bubbles, the charging pump suction provides a mixing element that makes sure only small bubbles enter the pump. Since out-gassing of dissolved gases can not be avoided when the pump is not operating, venting lines with motor-operated isolation valves are installed at the charging pump suction. This vent valve is opened when the charging pump is started and is closed after the charging pump has been operating for approximately 60 seconds.

Reactor Makeup and Inventory Control

During normal operation, the RCS inventory is maintained at a constant value by varying the letdown flow with a constant charging flow.

During a power increase, the reactor coolant expands as its temperature rises. Depending on the power level, the pressurizer absorbs these expansions as the level setpoint varies in a range designed for this purpose. If the pressurizer level increases above its setpoint, then the HP reducing valve opens to increase the letdown flow and reduce the pressurizer level to its setpoint. This excess water is drained to the VCT.

If the level in the VCT increases above its upper setpoint, a three-way valve partially diverts some of the letdown flow to the CSSS. If the level continues to increase above the upper setpoint, the total letdown flow is diverted to the CSSS tanks.

If the charging flow is greater than the letdown flow, the level in the VCT may reach the low-level setpoint. In this event, the VCT level decreases below the low-level setpoint and the VCT level is automatically adjusted. A signal initiates an automatic makeup from the reactor boron and water makeup system. This makeup automatically injects boric acid and demineralized water at rates such that the boron concentration of the makeup water corresponds to the RCS boron concentration. In the event the VCT level reaches its low-low level, the charging pump suction automatically switches to the IRWST.

Two boric acid storage tanks are provided and separated by MOVs. Each tank is initially filled with four percent boric acid (approximately 7000 ppm boron) and has an available volume of approximately 3250 ft^3. Each tank has its own boric acid makeup pump for providing the required amount of boric acid to the charging pump suction. A flow diagram of the reactor boron and water makeup system (RBWMS) is shown in Figure 9.3.4-4—Reactor Boron and Water Makeup System.

The demineralized water pumps that take suction from the storage tanks in the CSSS provide the demineralized water. There are six coolant storage tanks (11 through 16). Each has an available volume of approximately 4061 ft^3. A flow diagram of the CSSS is shown in Figure 9.3.4-5—Coolant Supply and Storage System.

Initially, tanks 11 through 14 are full of demineralized water and tanks 15 and 16 are empty. As reactor coolant makeup is required, the aligned boric acid storage tank provides boric acid and the CSSS tanks provide demineralized water in sequence starting with tank 14 and ending with tank 11.

As adjustments to the RCS boron concentration are required because of plant conditions (i.e., plant heatup, startup, shutdown, load follow, and to compensate for fuel burnup), demineralized water is added or a blended makeup is performed. This added water to the RCS results in the increase of the VCT level above its setpoint, which requires the discharge of reactor coolant to the CSSS. As reactor coolant discharges, water transfers sequentially into tank 16 of the CSSS first and then into tank 15. When tank 16 is approximately 55 percent full, a signal is initiated to generate processing water from the tank in the coolant treatment system (CTS). The CTS produces demineralized water and recovers the boron for reuse.

Refer to Section 12.3.6.5.3 for coolant supply and storage system design features which demonstrate compliance with the requirements of 10 CFR 20.1406.

Coolant Treatment and Boron Recovery

The CVCS discharges water to the CSSS, which contains boron ranging from refueling concentration to approximately zero ppm. The CTS processes this water. A flow diagram of the CTS is shown in Figure 9.3.4-6—Coolant Treatment System.

In general, evaporation separates the coolant into a concentrated boric acid solution at four percent H_3BO_3 and demineralized water. Due to the low vapor pressure of boric acid at the boiling temperature of water, the vapor generated by the evaporator has a low boric acid concentration. The vapor passes through a series of trays in the boric acid column, which further removes boric acid from the vapor.

An evaporator feed pump pumps borated water from the CSSS tank through a mixed bed ion exchanger in the purification system. Following purification, the water is preheated and fed into the boric acid column. The water in the column sump circulates through the tube side of the evaporator by natural circulation and is evaporated. Most of the heat required for evaporation leaves the column with the vapor. This vapor heat is utilized by compressing the vapor, which increases its temperature. Then the vapor is discharged to the shell side of the evaporator. This process condenses the vapor so it can be collected in a condensate tank. The condensate pumps transfer the condensate to the CSSS for reuse in the CVCS makeup.

The boric acid solution in the boric acid column is measured and controlled to maintain its boric acid concentration at an approximately constant four percent by weight which corresponds to 7000 ± 100 ppm boron. The boric acid solution is cooled and transferred to the RBWMS storage tanks for reuse in the CVCS makeup.

Since the ^{10}B concentration of boric acid depletes during the cycle, the recovered boric acid will typically have a different ^{10}B assay than the boric acid in the RCS. To maintain reactivity control during makeup operations, the ^{10}B assay of the boric acid sources must be known. Therefore, the ^{10}B assay of the RBWMS tanks will be measured after boric acid additions to confirm that any differences in ^{10}B abundance between the makeup source and the reactor coolant are accommodated.

If the condensate produced by the evaporator requires degasification, it can be discharged to the degasification unit prior to its discharge to the CSSS tanks.

9.3.4.2.2 Component Description

A summary of design data for the major components of the CVCS is provided in Table 9.3.4-1—Major CVCS Component Design Data.

Charging Pumps

The charging pumps are multistage, vertical centrifugal pumps. Design parameters for the charging pumps are given in Table 9.3.4-1. In the event the charging line isolates, a minimum flow recirculation line protects the charging pump. A single charging pump operates during normal plant operating conditions. However, both charging pumps can be placed into operation during plant conditions that require an increased flow rate. In the event of a loss of inventory because of an instrument line break, a single charging pump provides sufficient makeup to the RCS.

Each charging pump is provided with seal water to prevent reactor coolant leakage along the pump shaft. The seal water is provided by the seal water supply system, which is described in Section 9.2.7. The CVCS pumps trip on loss of seal water supply.

Regenerative Heat Exchanger

The regenerative heat exchanger recovers heat from the letdown flow stream and reheats the charging stream simultaneously. The heat exchanger is a horizontal U-tube counter flow design with the letdown passing through the tubes and the charging flow passing through the shell. Design parameters for the regenerative heat exchanger are given in Table 9.3.4-1.

High Pressure Coolers

The HP coolers use component cooling water to cool the letdown flow to a temperature acceptable for demineralizer operation. During normal plant operation, each HP cooler is capable of cooling the total letdown flow that has been precooled by the regenerative heat exchanger. The HP coolers support the heatup of the RCS and purification and degasification during hot shutdown conditions with high flow rates.

The HP coolers are a U-tube counter flow design. The letdown flow from the RCS passes through the tubes, while the cooling water from the CCWS passes through the heat exchanger shell. Design parameters for the HP coolers are given in Table 9.3.4-1.

High Pressure Reducing Stations

The two HP reducing stations reduce the pressure to a value compatible with the design pressure of the purification and treatment systems. Both reducing stations operate in parallel.

To maintain the RCS mass at the specified value according to various operating conditions, the letdown flow is regulated as a function of the pressurizer level. For this purpose, the HP reducing station is the actuating element for the pressurizer water level control system.

The control range of the HP reducing station covers a wide range of operating conditions. Thus, the mode of operation for the reducing station depends on the mode of operation for the pressurizer water level control system.

The HP reducing valves are austenitic stainless steel and bellows provide the shaft sealing.

Low Pressure Reducing Station

When the RHRS removes core decay heat, the LP reducing station is the actuating element of the pressurizer water level control system.

Through a switch over control, the LP reducing station controls the mid-loop level during an outage.

The LP reducing valve is austenitic stainless steel and bellows provide the shaft sealing.

Coolant Filters

The three coolant inlet filters remove insoluble particulate from the letdown flow to protect the ion exchanger resin. The cartridge filters pass the full letdown flow even when the filters are at their maximum allowable differential pressure. Since the filters are replaced remotely, access to the filter room is not necessary.

Mixed Bed Ion Exchangers

Coolant Purification Ion Exchangers - Both mixed bed ion exchangers are filled with the same ratio of cation to anion resin. The ion exchangers allow the full letdown flow through the bed and continuously remove radionuclides from the reactor coolant. The ion exchangers allow the removal of spent resin and their replacement with new resin.

Coolant Treatment Ion Exchanger - This mixed bed ion exchanger removes cesium and dissolved impurities from the coolant prior to treatment in the CTS. The construction of this ion exchanger is smaller, yet similar to the coolant purification ion exchangers.

Volume Control Tank

The VCT provides surge capacity for a portion of the reactor coolant which the pressurizer can not accommodate. The VCT has a total volume of approximately 671 ft^3 and a normal operating water volume of approximately 320 ft^3. In the event of a loss of letdown flow, the volume of the VCT is large enough to provide a continuous flow at the charging pump suction to allow automatic switchover to the IRWST suction.

The gaseous waste processing system maintains the VCT at a constant pressure by providing a continuous feed and bleed of gas to the tank. This sweeping process continuously removes fission gasses and hydrogen from the tank. The CVCS low pressure and holdup tanks that contain primary system water are continuously vented to prevent a vacuum condition. Design parameters for the VCT are given in Table 9.3.4-1.

Water Jet Pump

The water jet pump associated with the mixing pipe and the gas separator supplies the reactor coolant with the required hydrogen content.

The component is an austenitic stainless steel block containing three nozzles; one for the propellant liquid, one for hydrogen suction, and one for the discharge of the mixture. The pump has no moving parts. A diffuser with a reduced cross-section is installed inside the pump through which the propellant liquid passes in a jet-form, which increases the velocity of the liquid. This causes a pressure decrease in the adjacent regions, which results in the injection of hydrogen from the gas separator. The gas suctioned is entrained by the liquid stream and injected into the reactor coolant letdown flow.

In the event the shutoff valves on the discharge side of the pump and at the hydrogen suction line are closed, the design conditions are sufficient to prevent component failure. Design parameters for the water jet pump are given in Table 9.3.4-1.

Seal Water Injection Filters

Two seal water injection filters are installed in parallel in the common line to the RCP seals. They are sized to filter material that could be detrimental to the seal faces. Each filter is sized to accept flow in excess of the normal seal water flow requirements.

Differential pressure instrumentation measures the pressure drop across each filter and initiates an alarm in the MCR when the differential pressure is high.

Seal Water Return Filter

This filter collects particulate from the RCP seals. Differential pressure instrumentation measures the pressure drop across the filter and initiates an alarm in the MCR when the differential pressure is high.

9.3.4.2.3 System Operation

9.3.4.2.3.1 Plant Startup

Plant startup consists of the operations that bring the reactor from the cold shutdown condition to normal, no-load, and hot shutdown operating pressure and temperature. During the plant startup the CVCS fills the RCS, provides the required RCP seal injection flow, and controls the reactor coolant inventory and chemistry during the heatup.

To remove oxygen (usually after refueling) from the reactor coolant, a three-way valve diverts the letdown flow to the CDS. Before the reactor coolant temperature reaches 250°F, lithium hydroxide can be added to the reactor coolant at the charging pump suction to control the pH value of the reactor coolant. When the chemical characteristics of the reactor coolant are consistent with chemistry requirements, the hydrogenation station is placed in operation to provide the required hydrogen concentration in the reactor coolant to control dissolved oxygen during power operation.

During the pressurizer heatup, the LP reducing station is in service when the RHRS is connected to the RCS. When the reactor coolant pressure is above 365 psig, the LP reducing station is isolated and the normal letdown flow path provides letdown flow. During the RCS pressure increase, the pressurizer pressure is controlled by heaters and the auxiliary spray.

The RCPs are utilized for RCS heatup. During heatup, a three-way valve in the letdown line discharges excess coolant resulting from the expansion of the reactor coolant to the CSSS. Throughout the startup phase, the pressurizer level is maintained at its setpoint and the RCP seal injection flow rate to each operating pump is maintained at approximately 8 gpm.

9.3.4.2.3.2 Normal Operation

Normal operation includes hot standby and power operation.

9.3.4.2.3.3 Plant Shutdown

Plant shutdown takes the plant from a hot standby condition to a cold depressurized condition in preparation for maintenance or refueling.

After a plant shutdown, the reactor coolant boron concentration is increased prior to and during the cooldown and depressurization of the RCS. The RBWMS supplies borated water to the CVCS and the corresponding excess reactor coolant is diverted to the CSSS. At the completion of this operation, the RBWMS automatically provides any additional makeup at the required boron concentration.

If the reactor vessel is to be opened, the reactor coolant is degassed to remove fission gases and lower the hydrogen concentration by diverting letdown flow to the CDS.

The steam generators and the turbine bypass system perform the initial cooldown. During cooldown, the reactor coolant is cooled from approximately 595°F to 120°F. Coolant contraction is compensated to maintain a minimum letdown flow for purification and degasification and to maintain the required water level in the pressurizer. The resulting contraction at the beginning of the cooldown is so large that the letdown flow would be reduced to a minimum value if only one charging pump were in operation. Therefore, the initial cooldown is performed with two CVCS charging pumps in operation.

When the RCS temperature is about 250°F, the RHRS is connected to the RCS. The low head safety injection (LHSI) and RHR heat exchangers continue the cooldown. When the temperature downstream of the LHSI and RHR heat exchangers is approximately 130°F and primary pressure is approximately 350 psig, the HP reducing stations are isolated and the LP reducing station is opened.

After depressurization of the RCS, CVCS charging pumps are secured and bypassed, and the LHSI and RHR pumps inject water into the RCP seals or the RCP seal injection flow may be isolated.

To permit purification of the reactor coolant, the pressurizer level control system is switched from the HP reducing station to the LP reducing station at an RCS temperature of approximately 130°F, and the HP reducing station is closed. Reactor coolant, downstream of the LHSI and RHR heat exchangers, flows to the LP reducing station into the CVCS letdown line then through the CPS. The discharge from the CPS is returned to the letdown line and bypasses the VCT and charging pumps and is returned to the RCS via the charging lines.

9.3.4.2.3.4 Abnormal Operation

During abnormal operation, the CVCS continues to operate as designed. If a malfunction results in the letdown temperature exceeding that required for purification or degasification, those systems are automatically bypassed and the CVCS continues normal operation. In the event of a faulty closure of a charging line valve, a minimum flow valve opens and recirculates charging flow to the VCT to protect the charging pumps. Other abnormal operating conditions can result in a dilution incident or a loss or gain in reactor coolant inventory.

Four online boron concentration measurement instruments are installed on the charging line, upstream of the branch line to the seal water to measure the boron concentration of the total charging flow. The online boron meters are a half shell design and are not in contact with the reactor coolant. The neutron absorption effect of Boron-10 is used to measure the concentration of boron. The number of neutrons passing through the fluid depends on its Boron-10 content. The measured count rate is used to calculate the boron concentration. To improve the accuracy of the measurement, the temperature of the reactor coolant at the measuring point is used to adjust the boron concentration.

If the boron concentration decreases below a setpoint to indicate a possible dilution event, a signal is sent to isolate the charging pump suction. Three safety-related MOVs automatically isolate the normal letdown line and the line from the VCT. The closure of these three safety-related valves terminates the dilution event. Simultaneously, a non-safety-related valve opens aligning the charging pump suction to the IRWST, the charging line isolation valves are closed and the three-way valve to the coolant storage and supply tanks fully opens. The charging flow to the RCP seal water system remains in service during this evolution. These actions are performed by non-safety-related equipment and are not credited in the safety analysis.

9.3.4.2.3.5 Accident Conditions

During accident conditions, the CVCS continues to operate normally unless an SIS actuation, containment isolation signal (CIS) (refer to Section 6.2.4) or a high pressurizer level signal is received. In the event of an SIS actuation, the RCPB valves in the letdown line isolate. In the event a CIS (Stage 1) is actuated, the CVCS letdown line isolates while the RCP seal injection and leakoff, and CVCS charging continue to operate normally. If a CIS (Stage 2) is actuated, the RCP seal injection and leakoff lines, as well as the charging line, isolate. The charging pumps continue to operate on minimum flow recirculation. The CVCS mitigates a reactor coolant inventory increase event (refer to Section 15.5.2). Upon a high pressurizer level, the charging line isolation valve, the auxiliary spray isolation valve, and the charging line CIV close.

In the event of a Station Blackout (SBO) the CVCS letdown line is automatically isolated at the onset of the SBO.

The CVCS mitigates a boron dilution event (refer to Section 15.4.6). The sequence of events for the CVCS is described in the preceding section (Section 9.3.4.2.3.4).

The CVCS components and valve operators are provided with backup and emergency power and are available following a LOOP. If the RCPs are not operating, the CVCS auxiliary spray line provides auxiliary spray.

Interfacing System Loss of Coolant Accident

Breaks of the CVCS Outside the Containment - In the event of a letdown line break in the FB during normal plant operation, the break flow has a temperature of approximately 120°F. This leakage can be identified by:

- Pressure and temperature measurements in the letdown line.
- Alarm interlocking: initiated by the VCT low water level.
- Sump high water level in the FB vent and drain system.
- Increased activity measurements in the exhaust air ducts of the FB ventilation system for noble gas, airborne, and iodine radiation monitors (refer to Sections 9.4.2 and 11.5.3.1.7 and Table 11.5-1, Monitors R-17 and R-18).

A manual isolation of the letdown line after 30 minutes results in an inventory loss of a maximum of 9625 gallons of coolant. When the break is identified, closing any one of the four HP isolation valves in series isolates the letdown flow.

In the event of a line break upstream of the check valves, redundant check valves close preventing backflow from the charging line. Also, a low charging pump discharge pressure trips the charging pumps, which terminates the charging flow.

Tube Rupture in the HP Cooler - The CCWS cools the CVCS HP coolers in the RB. An HP cooler tube rupture results in a leak from the CVCS into the component cooling system. If the leak occurs during plant operation, the differential pressure inside to the outside of the tubes is approximately 2160 psi (CVCS pressure – CCWS pressure). In this event, the tube break in the CVCS HP cooler results in a leak of reactor coolant into the component cooling water.

The opening of the component cooling relief valve protects the CCWS piping and CIVs and prevents the overpressurization of the CCWS. An increased flow from the CCWS flow meters or an increase in radioactivity measured by detectors in the component cooling water inlet and outlet to the cooler can indicate the leak. This high activity measurement generates a signal to automatically close the cooler isolation valves to isolate the CVCS HP cooler.

Postulated System Leaks in Containment - In the event of a leak in the CVCS or RCP seal water system, reactor coolant with temperatures between approximately 120°F and 565°F is released. This leakage can be detected by activity measurements (area dose rate monitoring system) inside containment, and also by the CVCS pressure, temperature and flow conditions and the pressurizer level.

Postulated System Leaks in the Fuel Building - In the event of a CVCS or RCP seal water system leak in the Fuel Building, reactor coolant with temperatures of approximately 120°F is released.

Due to the loss of reactor coolant, the following alarms are also generated:

- VCT low water level.
- Sump high water level in the FB vent and drain system.

Overpressure Protection

Overpressure protection of the CVCS is afforded by relief valves that provide assurance that no section of the CVCS is pressurized above its design pressure as a result of improper operation or component malfunction.

9.3.4.3 Safety Evaluation

The design of safety-related portions of the CVCS satisfies GDC 1 regarding CVCS components being designed, fabricated, erected and tested to quality standards commensurate with the importance of the safety functions to be performed.

Consistent with the guidance in RG 1.26, Table 3.2.2-1 provides the seismic design and other design classifications of components in the CVCS.

The design of safety-related portions of the CVCS satisfies GDC 2 regarding the effects of natural phenomena.

- Safety-related portions of the CVCS are located in the RB and FB. These buildings are designed to withstand the effects of earthquakes, tornadoes, hurricanes, floods, tsunami and seiches. Section 3.3, Section 3.4, Section 3.5, Section 3.7 and Section 3.8 provide the bases for the adequacy of the structural design of the buildings.
- Safety-related portions of the CVCS are designed to remain functional during and after a safe shutdown earthquake (SSE). Sections 3.7 and 3.9 provide the design loading conditions that are considered. Sections 3.5, 3.6 and 9.5.1 provide the hazards analyses to make sure that a safe shutdown, as outlined in Section 7.4, is achieved and maintained.
- The CVCS meets the guidance provided in RG 1.29, Position C.1, for safety-related portions of the system, and Position C.2 for non-safety-related portions.

The design of safety-related portions of the CVCS satisfies GDC 5 regarding sharing of systems.

- Safety-related portions of the CVCS are not shared among nuclear power units.

The design of safety-related portions of the CVCS satisfies GDC 14 regarding maintaining RCPB material integrity by means of the CVCS being capable of maintaining RCS water chemistry necessary to meet PWR RCS water chemistry specifications.

- The CVCS provides flow to the CPS and CDS to maintain acceptable purity levels in the reactor coolant. The CVCS also provides chemical additions to the RCS to maintain the reactor coolant within requirements. Water chemistry requirements of the CVCS meet those specified for the RCS, which are based on the latest revision of the EPRI PWR Primary Water Chemistry Guidelines (Reference 1), and are augmented, as appropriate, for the U.S. EPR, because of improved metallurgy.

GDC 29 requires that safety-related portions of the CVCS reliably provide negative reactivity to the reactor by supplying borated water to the RCS in the event of AOOs; if the plant design relies on the CVCS to perform the safety function of boration for mitigation of DBEs.

- The CVCS is not designed to perform the safety function of RCS boration for the mitigation of DBEs.
- The CVCS is designed to supply borated water to the RCS during normal power operating conditions. To provide assurance that this operational function is satisfactorily performed, the design of components and instrumentation associated with this function are redundant.

GDC 33 and GDC 35 require that safety-related portions of the CVCS supply reactor coolant makeup in the event of small breaks or leaks in the RCPB and to function as part of the ECCS assuming a single active failure coincident with a LOOP; if the plant design relies on the CVCS to perform the safety function of safety injection as part of the ECCS.

- The CVCS is designed to supply reactor coolant makeup in the event of small breaks or leaks in the reactor coolant pressure boundary. The CVCS is designed with both on-site and off-site electric power and meets GDC 33.
- The CVCS is not designed to perform the safety function of the ECCS during a DBA. Therefore, GDC 35 is not applicable to the CVCS.

The design of safety-related portions of the CVCS satisfies GDC 60 regarding vents and drains containing gaseous and liquid radioactive material through closed systems.

- The CVCS component vents and drains are piped to the nuclear island vent and drain system (NIDVS), which allows storage and processing of the discharged liquids. The gases discharged from the CVCS are collected and processed in the gaseous waste processing system.

The design of safety-related portions of the CVCS satisfies GDC 61 regarding the assurance of adequate safety under normal and postulated accident conditions.

- The CVCS design permits periodic inspections with suitable shielding for radiation protection and with appropriate containment, confinement and filtering systems. To allow personnel access to different system components while maintaining exposure low, radioactive components are separated from non-radioactive components.

The design of safety-related portions of the CVCS satisfies 10 CFR 50.34(f)(2)(xxvi) regarding detection of reactor coolant leakage outside containment by providing leakage control and detection systems in the CVCS and implementation of appropriate leakage control program.

- The CVCS isolates components or piping so that the CVCS safety function is not compromised. Design provisions include the capability to identify and isolate the leakage or malfunction, and to isolate the non-safety-related portions of the system.

10 CFR 50.63 identifies the requirements for withstanding or coping with, and recovering from an SBO event.

- The CVCS provides automatic isolation of the letdown line at the onset of an SBO event.

9.3.4.4 Inspection and Testing Requirements

The CVCS components are inspected and tested as part of the initial test program. Refer to Section 14.2 (test abstracts #002, #003, #004, #005, #006, #007, #008, #009, #010, #011, #126, #173 and #176) for initial plant startup test program. Section 5.2 and Section 6.6 provide the ASME Boiler and Pressure Vessel Code, Section XI (Reference 2) requirements that are appropriate for the CVCS.

9.3.4.5 Instrumentation Requirements

The instrumentation and control (I&C) functions are normally performed from the MCR by the Process Information and Control System (PICS). In the event the PICS is not available, CVCS actuators that provide a safety function are operated from the Safety Information and Control System (SICS).

Process control instrumentation is provided to acquire data concerning key parameters about the CVCS.

The instrumentation furnishes input signals to monitor or generate alarms. Indications or alarms are provided for pressure, temperature, flow, level and boron concentration. The instrumentation also supplies input signals for control purposes. Specific control functions are described as follows:

Pressure Instruments

- Pressure downstream of the HP reducing station—A high pressure signal initiates an alarm in the MCR and the closure of the HP reducing valves and HP cooler outlet isolation valves.

- Pressure downstream of the LP reducing station—A high pressure signal initiates an alarm in the MCR and the closure of the LP reducing valve and LP reducing station outlet isolation valve.

- VCT pressure high or low—A high VCT pressure initiates an alarm in the MCR and the closure of the nitrogen gas supply valve. A low VCT pressure initiates an alarm in the MCR.

- Charging pump suction pressure low—A low charging pump suction pressure initiates an MCR alarm and the tripping of the operating charging pump(s).

- Charging pump discharge pressure high or low—A high discharge pressure initiates an MCR alarm and trips the operating charging pump. A low discharge pressure initiates an MCR alarm, the closure of the charging line control valve and the tripping of the operating charging pump(s).

- Charging pump seal water pressure low—A low charging pump seal water pressure initiates an MCR alarm and the tripping of the operating charging pump(s).

- RCP seal water injection filter differential pressure high—A high differential pressure initiates an MCR alarm and the closure of the outside CIV.

- RCP seal water leakoff filter differential pressure high—A high differential pressure initiates an MCR alarm, the opening of the isolation valve that directs the seal leakoff water to the vent and drain system, and the closure of the inside CIV.

- Coolant purification inlet filter or mixed bed ion exchanger differential pressure high—A high differential pressure across either initiates an MCR alarm and the closure of the three-way inlet valve from the letdown line bypassing the CPS.

Temperature Measurements

- Letdown temperature upstream of the regenerative heat exchanger—This temperature is compared to the temperature of the charging flow downstream of the regenerative heat exchanger. A high differential temperature isolates the charging line and the trips the operating charging pump(s).

- Letdown temperature downstream of the HP cooler high or low—A low temperature initiates an MCR alarm. A high temperature initiates an MCR alarm, the closure of the HP reducing valve, and the closure of the HP cooler outlet isolation valve.

- Letdown temperature downstream of the HP reducing station high or low—A low temperature initiates an MCR alarm. A high temperature initiates an MCR alarm, the closure of the three-way valve bypassing the CPS, the closure of the three-way valve bypassing the CDS, and the closure of the LP reducing station valve.

Flow Measurements

- RCP seal water inlet flow low—A low seal water flow initiates an MCR alarm.
- Letdown flow downstream of the HP and LP reducing stations low—A low flow initiates an MCR alarm.
- Charging pump flow downstream of each charging pump high—A high charging flow initiates an MCR alarm and the closure of the charging flow control valve.
- Charging flow upstream of the regenerative heat exchanger high or low—A low flow initiates an MCR alarm. A high flow initiates an MCR alarm and the closure of the charging flow control valve.

Level Measurements

- VCT level high or low—As the level decreases from its normal setpoint, a low-level results in the RBWMS supply initiating automatic makeup, an MCR alarm, and the tripping of one charging pump if two are operating. A minimum level initiates an MCR alarm, the closure of the redundant charging pump suction valves from VCT and letdown line, and the opening of the isolation valve from the IRWST to the charging pump suction. A high level initiates an MCR alarm and the diversion of letdown to the CSSS.

Boron Concentration Measurement

- Charging line boron concentration below setpoint—A charging flow measured boron concentration below its setpoint value initiates an MCR alarm, the closure of the redundant charging pump suction valves from the VCT and letdown line, and the opening of the isolation valve from the IRWST to the charging pump suction.

9.3.4.6 References

1. EPRI Report 1014986, “PWR Primary Water Chemistry Guidelines,” Revision 6, Electric Power Research Institute, December 2007.
2. ASME Boiler and Pressure Vessel Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components,” The American Society of Mechanical Engineers, 2004.

Table 9.3.4-1—Major CVCS Component Design Data
Sheet 1 of 5

Design Parameter		Value
Main System Design Data, CVCS	Design pressure	3625 psig
	Design temperature	684°F
Charging Pump	Number	2
	Type	Centrifugal
	Flow rate min.	40 gpm
	Flow rate normal	176 gpm
	Flow rate max.	285 gpm
	Discharge head @ zero flow	6890 ft
	Discharge head normal	5940 ft
	Discharge head at max. flow	4373 ft
	Design pressure	3625 psig
	Design temperature	212°F
	Power consumption (approx.)	434 kW
	Material	Austenitic stainless steel
Volume Control Tank	Number	1
	Volume gross/net	671 / 600 ft^3
	Design pressure	175 psig / -14.5psig
	Design temperature	212°F
	Operating pressure	24.6 / 40.6 psig
	Operating temperature	122°F
	Material	Austenitic stainless steel
Regenerative Heat Exchanger	Number	1
	Type	U-tube
	Heat output (during operation with 2 charging pumps)	Approx. 16,450 kW
Tube Side (Reactor Coolant, Letdown Line)	Flow rate	2650 lb/min
	Inlet temperature	565°F
	Outlet temperature	240°F
	Design pressure	3045 psig
	Design temperature	664°F
	Material	Austenitic stainless steel

Table 9.3.4-1—Major CVCS Component Design Data
Sheet 2 of 5

Design Parameter		Value
Shell Side (Reactor Coolant, Charging Line)	Flow rate	2490 lb/min
	Inlet temperature	120°F
	Outlet temperature	487°F
	Design pressure	3045 psig
	Design temperature	664°F
	Material	Austenitic stainless steel
High Pressure Cooler	Number	2
	Type	U-tube
	Heat output (during operation with 2 charging pumps)	Approx. 5420 kW
Tube Side (Reactor Coolant, Letdown Line)	Flow rate	2650 lb/min
	Inlet temperature	240°F
	Outlet temperature	120°F
	Design pressure	3045 psig
	Design temperature	664°F
	Material	Austenitic stainless steel
Shell Side (Component Cooling Water)	Flow rate	7940 lb/min
	Inlet temperature	95°F
	Outlet temperature	135°F
	Design pressure	175 psig
	Design temperature	338°F
	Material	Austenitic stainless steel
Water Jet Pump	Number	1
	Type	Water jet pump
	Flow rate normal (hydrogen, approx.)	1.63 ft^3/min
	Propellant liquid (reactor coolant, approx.)	4.3 gpm
	Discharge head	49.2 ft
	Design pressure	3625 psig
	Design temperature	212°F
	Material	Austenitic stainless steel

Table 9.3.4-1—Major CVCS Component Design Data
Sheet 3 of 5

Design Parameter		Value
Gas Separator	Number	1
	Volume (approx.)	14 ft^3
	Design pressure	175 psig
	Design temperature	212°F
	Material	Austenitic stainless steel
Boron Concentration Measurement Devices [1]	Number	4
	Type	Online measurement based on neutron absorption, with unabsorbed neutrons are detected by counter tubes
	Neutron source	Am/Be
	Length	Approx. 25.6 in
	Diameter	Approx. 11.8 in
	Weight	Approx. 110 lb
	Installed on the charging line (no contact with system fluid)	
Automatic Recirculation Valve	Number	2
	Nominal diameter inlet/outlet/ bypass	4 / 4 / 2 in
	Design temperature	212°F
	Operating temperature	Approx. 122°F
	Design pressure	3625 psig
	Minimum flow through HP charging pump	40 gpm
HP Reducing Station	Nominal diameter	3 in
	Design pressure	3045 psig
	Design temperature	664°F
	Type	Control valve
	Cv min / norm / max	Approx. 0.5 / 3 / 14

Table 9.3.4-1—Major CVCS Component Design Data
Sheet 4 of 5

Design Parameter		Value
LP Reducing Station	Nominal diameter	4 in
	Design pressure	1160 psig
	Design temperature	664°F
	Type	Control valve
	Cv min / norm / max	Approx. 2 / 27 / 77
Coolant Filters	Number	3
	Type	Cartridge filter
	Volume gross/net	7.0 / 7.0 ft^3
	Design pressure	175 / -14.5 psig
	Design temperature	212°F
	Operating pressure	70–115 psig
	Operating temperature	122°F
	Retention rate	10.0 micron
	Efficiency	98 percent
	Material	Austenitic stainless steel
Coolant Purification Mixed Bed Ion Exchanger	Number	2
	Type	Pressure tank with toro-spherical head
	Total volume	120 ft^3
	Resin volume	70 ft^3
	Design pressure	175 / -14.5 psig
	Design temperature	212°F
	Operating pressure	70 psig
	Operating temperature	122°F
	Sieve tray gap width	200 micron
	Material	Austenitic stainless steel

Table 9.3.4-1—Major CVCS Component Design Data
Sheet 5 of 5

Design Parameter		Value
Coolant Treatment Mixed Bed Ion Exchanger	Number	1
	Type	Pressure tank with toro-spherical head
	Total volume	45 ft^3
	Resin volume	21 ft^3
	Design pressure	175 / -14.5 psig
	Design temperature	212°F
	Operating pressure	130–145 psig
	Operating temperature	68–122°F
	Sieve tray gap width	200 micron
	Material	Austenitic stainless steel
RCP Seal No.1 Injection Filter	Number	2
	Type	Cartridge filter
	Material	Austenitic stainless steel
	Design pressure	3045 psig
	Design temperature	212°F
	Flow rate (normal)	32 gpm
	Retention rate	1–5 microns
	Retention efficiency	98–100%
RCP Seal Leakoff Filter	Number	1
	Type	Cartridge filter
	Material	Austenitic stainless steel
	Design pressure	175 psig
	Design temperature	212°F
	Flow rate (normal)	12.7 gpm
	Retention rate	1–5 microns
	Retention efficiency	98–100%

Notes:

1. To allow conversion from ^{10}B concentration to total boron concentration, monthly grab samples for ^{10}B assay are performed.