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6.3 CHEMICAL AND VOLUME CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the Chemical and Volume Control System (CVCS).

2. Describe the major differences between the AP1000 and current operating Westinghouse plants Chemical and Volume Control Systems.

6.3.1 Introduction

The chemical and volume control system is designed to perform the following major functions:

- **Purification** - maintain reactor coolant system fluid purity and activity level within acceptable limits.

- **Reactor coolant system inventory control and makeup** - maintain the required coolant inventory in the reactor coolant system; maintain the programmed pressurizer water level during normal plant operations.

- **Chemical shim and chemical control** - maintain the reactor coolant chemistry conditions by controlling the concentration of boron in the coolant for plant startups, normal dilution to compensate for fuel depletion and shutdown boration, and provide the means for controlling the reactor coolant system pH by maintaining the proper level of lithium hydroxide.

- **Oxygen control** - provide the means for maintaining the proper level of dissolved hydrogen in the reactor coolant during power operation and for achieving the proper oxygen level prior to startup after each shutdown.

- **Filling and pressure testing the reactor coolant system** - provide the means for filling and pressure testing the reactor coolant system. The chemical and volume control system does not perform hydrostatic testing of the reactor coolant system, which is only required prior to initial startup and after major, nonroutine maintenance, but provides connections for a temporary hydrostatic test pump.

- **Borated makeup to auxiliary equipment** - provide makeup water to the primary-side systems that require borated reactor-grade water.

- **Pressurizer Auxiliary Spray** - provide pressurizer auxiliary spray water for depressurization.

The chemical and volume control system removes radioactive corrosion products, ionic fission products, and fission gases from the reactor coolant system to maintain low reactor coolant system activity levels. The chemical and volume control system purification capability considers occupational radiation exposure (ORE) to support ALARA goals.

The chemical and volume control system is designed to maintain the reactor coolant system activity level at less than the technical specification limit for normal operations, with design-basis fuel defects. The technical specifications allow these limits to be exceeded for a specified duration.

The purification rate is based on minimizing occupational radiation exposure and providing access to the reactor coolant system equipment. The chemical and volume control system provides a reactor coolant system purification rate of at least one reactor coolant system mass per 16 hours.

The chemical and volume control system has sufficient reactor coolant system purification and degasification capability (in conjunction with the liquid radioactive waste system) to allow the reactor vessel head to be removed in a timely manner during a refueling shutdown. In addition, purification during shutdowns has a positive impact on the occupational radiation exposure to workers during the outage. The chemical and volume control system supports the plant ALARA goals with the shutdown purification function.

The chemical and volume control system provides a means to add and remove mass from the reactor coolant system, as required, to maintain the programmed inventory during normal plant operations. Operations that are accommodated include startup, shutdown, step load changes, and ramp load changes.

The chemical and volume control system is capable of maintaining a constant volume in the reactor coolant system, while the plant is being heated up or cooled down. During a heatup it is necessary to remove reactor coolant system mass due to expansion. The maximum rate of net expansion occurs at the end of the heatup, so the limiting case is based on controlling the pressurizer level during this phase of operation. This expansion is accommodated by the normal letdown path. During cooldown, it is necessary to add mass due to reactor coolant system shrinkage. The chemical and volume control system is capable of maintaining the minimum pressurizer level with makeup during cooldown from hot zero power to cold shutdown while maintaining normal purification flow. Ramp and step load changes, as well as load rejections, are accommodated by the reactor coolant system pressurizer level control system. The chemical and volume control system can function to accommodate normal pressurizer level control system makeup and letdown requirements.

The chemical and volume control system is designed to make up for leaks, including leaks up to 3/8-inch inside diameter and for anticipated steam generator tube leaks, allowing the plant to be taken to cold shutdown conditions without the use of safety-related makeup systems.

The chemical and volume control system provides the means to vary the boron concentration in the reactor coolant system. The system also controls the reactor coolant system chemistry for the purpose of limiting corrosion and enhancing core heat transfer.

The chemical and volume control system provides a means for filling and pressure testing the reactor coolant system. The chemical and volume control system also provides connections for a temporary hydrotest pump.

The chemical and volume control system provides makeup to the passive core cooling system accumulators, to the core makeup tanks, to the in-containment refueling water storage tank, and to the spent fuel pool at various boron concentrations.

The safety functions provided by the chemical and volume control system are limited to containment isolation of chemical and volume control system lines penetrating containment, termination of inadvertent reactor coolant system boron dilution, isolation of makeup on a steam generator or pressurizer high level signal, and preservation of the reactor coolant system pressure boundary, including isolation of normal chemical and volume control system letdown from the reactor coolant system.

6.3.2 System Description

The chemical and volume control system consists of regenerative and letdown heat exchangers, demineralizers and filters, makeup pumps, tanks, and associated valves, piping, and instrumentation. The system parameters are given in Table 6.3-1. A simplified diagram for the chemical and volume control system is included as Figure 6.3-1.

6.3.2.1 Ionic Purification

The normal chemical and volume control system purification loop is inside containment and operates at reactor coolant system pressure, utilizing the developed head of the reactor coolant pumps as the motive force for the purification flow. During power operations, fluid is continuously circulated through the chemical and volume control system from the discharge of one of the reactor coolant pumps. It passes through the regenerative heat exchanger where it is cooled by the returning chemical and volume control system flow, and is further cooled by component cooling water in the letdown heat exchanger to a temperature compatible with the demineralizer resins. The letdown fluid flows through a mixed bed demineralizer, optionally through a cation-bed demineralizer, and through a filter. It returns to the suction of a reactor coolant pump after being heated in the regenerative heat exchanger. The purification loop is at reactor coolant system pressure.

Since the motive force for the purification loop is the reactor coolant pump head in a closed loop with the reactor coolant system, continuous purification is provided without operating the chemical and volume control system makeup pumps.

The mixed-bed demineralizers are provided in the purification loop to remove ionic corrosion products and certain ionic fission products. The demineralizers also act as filters. One mixed-bed demineralizer is normally in service, with a second demineralizer acting as backup in case the normal unit should become exhausted during operation. Each demineralizer and filter is sized to provide a minimum of one fuel cycle of service without changeout.

The mixed-bed demineralizer in service can be supplemented by intermittent use of the cation-bed demineralizer for additional purification in the event of fuel defects. In this case, the cation resin removes mostly lithium and cesium isotopes. The cation-bed demineralizer has sufficient capacity to maintain the cesium-136 concentration in the reactor coolant below 1.0 microcurie per cubic centimeter with design basis fuel defects. Each mixed-bed and the cation-bed demineralizer is sized to accept the maximum purification flow. Filters are provided downstream of the demineralizers to collect particulates and resin fines.

During plant shutdowns when the reactor coolant pumps are stopped, the normal residual heat removal system provides the motive force for the chemical and volume control system purification. Purification flow from the normal residual heat removal system heat exchanger is routed directly through the normal chemical and volume control system purification loop. Boron changes and dissolved gas control are still possible by operating the chemical and volume control system in a semiclosed-loop arrangement.

6.3.2.2 Gaseous Purification

Removal of radioactive gases from the reactor coolant system is not normally necessary because the gases do not build up to unacceptable levels when fuel defects are within normally anticipated ranges. If radiogas removal is required because of high fuel defects, the chemical and volume control system can be operated by routing flow to the liquid radwaste system degassifier. In this configuration, the letdown fluid is depressurized by flowing through the letdown orifice. The letdown flow is routed outside of containment through the liquid radwaste system degassifier to one of the liquid radwaste system effluent holdup tanks. Coolant is returned to the reactor coolant system with the chemical and volume control system makeup pumps. This provides efficient gas removal.

Removal of radioactive gas and hydrogen during shutdown operations is necessary to avoid extending the maintenance and refueling outages. The reactor coolant system pressure boundary cannot be opened to the containment atmosphere until the gas concentrations are reduced to low levels. The shutdown degassing process is accomplished by operating the chemical and volume control system in the open loop configuration. In addition, a line is provided to allow the letdown orifice to be manually bypassed, so gas removal can continue after the reactor coolant system has been depressurized.

6.3.2.3 Reactor Coolant System Inventory Control and Makeup

Changes in reactor coolant volume are accommodated by the pressurizer level program for normal power changes, including transition from hot standby to full-power operation and returning to hot standby. In addition, the pressurizer has sufficient volume, within the deadband of the level control program, to accommodate minor reactor coolant system leakage for some time. The chemical and volume control system provides inventory control to accommodate minor leakage from the reactor coolant system, expansion during heatup from cold shutdown, and contraction during cooldown. This inventory control is provided by letdown and makeup connections to the chemical and volume control system purification loop.

6.3.2.4 Chemical Shim and Chemical Control

The chemical and volume control system provides the following functions to support the water chemistry and chemical shim requirements of the reactor coolant system:

- Means of addition and removal of pH control chemicals for startup and normal operation, and

- Means of addition and removal of soluble chemical neutron absorber (boron) and makeup water, at concentrations and rates compatible with normal plant operation.

Reactor coolant system chemistry changes are accomplished with a feed-and-bleed operation. The letdown and makeup paths are operated simultaneously and appropriate chemicals are provided at the suction of the reactor makeup pumps.

Reactor coolant system boron changes are required to compensate for fuel depletion, startups, shutdowns, and refueling.

To borate the reactor coolant system, the operator sets the makeup control system to automatically add a preset amount of boric acid by fully diverting the three-way valve in the pump suction to the boric acid storage tank, with delivered flow measured at the discharge of the makeup pumps. Dilution operates in a similar fashion. In either case, if the pressurizer level exceeds its control point, the letdown path to the liquid radwaste system holdup tanks is automatically opened.

The chemical agent used for pH control is lithium hydroxide (LiOH). This chemical is chosen for its compatibility with the material and water chemistry of borated water, stainless steel, zirconium systems. In addition, lithium-7 is produced in the core region because of irradiation of the dissolved boron in the coolant. A chemical mixing tank is provided to introduce the solution to the suction of the makeup pumps, as required to maintain the proper concentration of LiOH in the reactor coolant system.

The solution is poured into the chemical mixing tank and is then flushed to the suction manifold of the makeup pumps with demineralized water. A flow orifice is provided on the demineralized water inlet pipe to allow chemicals to be flushed into the reactor coolant system at acceptable concentrations.

The concentration of lithium-7 in the reactor coolant system varies according to a pH control curve as a function of the boric acid concentration of the reactor coolant system. If the concentration exceeds the proper value, as it may during the early stages of core life when lithium-7 is produced in the core at a relatively high rate, the cation bed demineralizer is used in the letdown path in series with the mixed bed demineralizer to lower the lithium-7 concentration. Since the buildup of lithium is slow, the cation bed demineralizer is used only intermittently. When letdown is being diverted to the liquid radwaste system, the letdown flow is routed through the cation bed demineralizer for removal of as much lithium-7 and cesium as possible.

The chemical and volume control system provides control of the reactor coolant system oxygen concentration, both during startup by introducing an oxygen scavenger and during power operations by driving toward zero the equilibrium concentration of oxygen produced by radiolysis in the core by injecting hydrogen.

During plant startup from cold conditions, an oxygen scavenging agent is used. The oxygen scavenger solution is introduced into the reactor coolant system via the makeup flow and chemical mixing tank, in the same manner as described for lithium-7 addition. The oxygen scavenger is used for oxygen control only at startup from cold shutdown conditions.

Dissolved hydrogen is employed during normal power operation to control and scavenge oxygen produced due to radiolysis of water in the core region. Hydrogen makeup is supplied to the reactor coolant system by direct injection of high-pressure gaseous hydrogen. The hydrogen comes from a bottle outside containment, through a containment penetration and is mixed in the chemical and volume control system purification loop. Hydrogen removal from the reactor coolant system is not necessary because hydrogen is consumed in the core.

6.3.2.5 Reactor Coolant System Filling and Pressure Testing

Reactor coolant system filling is accomplished by using the chemical and volume control system makeup pumps to provide fluid at the proper boron concentration (refueling), taking suction from both the boric acid storage tank and the demineralized water tank. The makeup pumps can also take suction from a clean liquid radwaste system holdup tank, by opening the line to the makeup pumps from that holdup tank.

The chemical and volume control system makeup pumps produce sufficient head to pressure test the reactor coolant system after maintenance and refueling.

A temporary hydrotest pump is required for initial hydrotesting, which requires higher pressures than can be achieved with the makeup pumps.

6.3.2.6 Borated Makeup

The makeup pumps are used to provide makeup at the proper boron concentration to the passive core cooling system accumulators, to the core makeup tanks, to the in-containment refueling water storage tank, and to the spent fuel pool. Makeup to these locations is at boric acid concentration as required, which can be varied from 0 to 4375 parts per million (2.5 weight percent). A mixture of 2.5 weight percent boric acid and demineralized water is provided by taking suction from both the boric acid storage tank and the demineralized water tank.

6.3.3 Component Descriptions

The general descriptions and summaries of the chemical and volume control system components are provided below. The key equipment parameters for the chemical and volume control system components are contained in Table 6.3-2. Refer to Figure 6.3-1 for component locations.

6.3.3.1 Chemical and Volume Control System Makeup Pumps

Two centrifugal makeup pumps are provided. These pumps are driven by ac motors, and flow is controlled by positioning a control valve in the common discharge line from the pumps. A cavitating venturi in the common discharge line limits the makeup flow and provides protection from excessive pump runout. Each pump has a recirculation loop with a heat exchanger and flow control orifice to provide adequate minimum flow for pump protection. The mini-flow heat exchanger is cooled by component cooling water.

The makeup pumps are arranged in parallel with common suction and discharge headers. Each provides full capability for normal makeup; thus, there is redundancy for normal operations. The normal makeup pump suction fluid comes from the boric acid storage tank and the demineralized water connection. A three-way valve in the suction header is positioned to provide a full range of concentrations.

One makeup pump is capable of maintaining normal reactor coolant system inventory with leaks up to a 3/8-inch inside diameter, without an actuation of the safety injection systems. The second pump can be manually started to provide additional reactor coolant makeup. These pumps are used to pressure test the reactor coolant system.

Parts of the pump in contact with reactor coolant are constructed of austenitic stainless steel. The pump motor and lube oil are air cooled.

6.3.3.2 Letdown Heat Exchanger

One single-shell pass U-tube letdown heat exchanger is provided. The heat exchanger is designed to cool the purification loop flow from the regenerative heat exchanger outlet temperature to the desired letdown temperature allowing the letdown to be processed by the demineralizers while maximizing the thermal efficiency of the chemical and volume control system.

The letdown heat exchanger outlet temperature is controlled by the operator by remotely positioning a component cooling system flow control valve.

The reactor coolant in the purification loop flows through the tubes, which are stainless steel, and component cooling water flows through the shell, which is carbon steel.

6.3.3.3 Miniflow Heat Exchangers

Two miniflow heat exchangers are provided, one in each makeup pump miniflow recirculation line. Each heat exchanger is designed to cool the flow through the chemical and volume control system makeup pump minimum flow recirculation lines to the desired temperature for pump protection. The makeup water flows through the tubes, which are stainless steel, and component cooling water flows through the shell, which is carbon steel.

6.3.3.4 Regenerative Heat Exchanger

One regenerative heat exchanger is provided. This heat exchanger is used to recover heat from the purification loop flow leaving the reactor coolant system by reheating the fluid entering the reactor coolant system. This provides increased thermal efficiency and also reduces thermal stresses on the reactor coolant system.

The design basis for this heat exchanger is the last hour of plant heatup, when expansion of the reactor coolant system requires a net removal of inventory. For this case the regenerative heat exchanger outlet temperature must be low enough to allow the letdown heat exchanger to cool the letdown to the desired temperature with anticipated cooling water temperatures.

The reactor coolant leaving the reactor coolant system flows through the tube side of this heat exchanger, and the returning fluid flows through the shell. This arrangement places the cleaner fluid on the shell side and the lower quality fluid on the tube side, where there are fewer crevices available for crud deposition.

6.3.3.5 Boric Acid Storage Tank

One boric acid storage tank is provided. The tank is sized to allow for one shutdown to cold shutdown followed by a shutdown for refueling at the end of the fuel cycle.

The tank is vented to the atmosphere. Relatively little boric acid is used during power operation, since load follow is accomplished with gray rods and without changes in the reactor coolant system boron concentration. Therefore, the boric acid which is injected has a negligible effect on the free oxygen level in the reactor coolant system.

The tank is a free-standing stainless steel cylindrical design, located outside of the buildings, with only normal freeze protection required to maintain solubility of the 2.5 weight percent boric acid.

6.3.3.6 Boric Acid Batching Tank

The boric acid batching tank is a cylindrical tank with an immersion heater used in the preparation of 2.5 weight percent boric acid. A mixer is included with the tank. The tank is constructed of austenitic stainless steel and is provided with fill, vent and drain connections.

6.3.3.7 Chemical Mixing Tank

The chemical mixing tank is a small vertical, cylindrical tank sized to provide sufficient capacity for injecting an oxygen scavenger solution necessary to provide a concentration of ten parts per million in the cold reactor coolant system for oxygen scavenging.

A variety of chemicals to be added to the primary system are mixed in the tank. The solution to be injected is placed into the mixing tank and then flushed to the suction of the makeup pumps with demineralized water.

The tank is constructed of austenitic stainless steel and is provided with fill, vent, and drain connections.

6.3.3.8 Cation-Bed Demineralizer

One cation-resin-bed demineralizer is located downstream of the mixed-bed demineralizers and is used intermittently to control the concentration of lithium-7 (pH control) in the reactor coolant system. The demineralizer is sized to accommodate maximum purification flow when in service, which is adequate to control the lithium-7 and/or cesium concentration in the reactor coolant.

The demineralizer vessel is designed for reactor coolant system pressure and is constructed of austenitic stainless steel, with connections for resin addition, replacement, flushing, and draining. The vessel incorporates a retention screen, an inflow screen, and mesh screens on the drain connections. The screens are designed to retain the resin with minimum pressure drop. The inflow screen prevents inadvertent flushing of the resin into the purification loop through the demineralizer inlet and also deflects the incoming flow to preserve a smooth resin bed.

6.3.3.9 Mixed-Bed Demineralizers

Two mixed-bed demineralizers are provided in the purification loop to maintain reactor coolant purity. A mixture of lithiated cation and anion resin is used in each demineralizer. Both forms of resin remove fission and corrosion products. Each demineralizer is sized to accept the full purification flow during normal plant operation and to have a minimum design life of one core cycle.

The construction of the mixed-bed demineralizers is identical to that of the cation-bed demineralizer.

6.3.3.10 Makeup Filter

One makeup filter is provided to collect particulates in the makeup stream, such as boric acid storage tank sediment. The filter is designed to accept maximum makeup flow. The unit is constructed of austenitic stainless steel with a disposable synthetic cartridge and is designed for reactor coolant system hydrostatic test pressure.

6.3.3.11 Reactor Coolant Filters

Two reactor coolant filters are provided. The filters are designed to collect resin fines and particulate matter from the purification stream. Each filter is designed to accept maximum purification flow.

The units are constructed of austenitic stainless steel with disposable synthetic cartridges and are designed for reactor coolant system pressure.

6.3.3.12 Chemical and Volume Control System Letdown Orifice

One letdown orifice is provided in the letdown line, where fluid leaves the high-pressure purification loop before it exits containment. The orifice limits the letdown flow to a rate compatible with the chemical and volume control system equipment and also plant heatup and dilution requirements.

The orifice consists of an assembly that provides for permanent pressure loss without recovery and is made of austenitic stainless steel.

A manual bypass line is provided around the orifice to allow shutdown purification and degassing when the reactor coolant system pressure is low.

6.3.3.13 Purification Stop Valves

These normally open, motor-operated valves are located inside containment and close automatically on a low pressurizer level signal from the protection and safety monitoring system to preserve reactor coolant pressure boundary and to prevent uncovering of the heater elements in the pressurizer. The valves fail "as is" on loss of power, and manual control (open/auto/close) is provided in the main control room and at the remote shutdown workstation.

6.3.3.14 Letdown Flow Inside Containment Isolation Valve

This normally closed, fail-closed, air-operated globe valve is located inside containment and isolates letdown to the liquid radwaste system. This valve automatically opens and closes on a plant control system signal from the pressurizer level control or a containment isolation signal from the protection and safety monitoring system. It automatically opens on high pressurizer level and closes when the pressurizer level returns to normal. It also closes on a high-high liquid radwaste system degassifier level or a containment isolation signal. This valve operator has a flow restricting orifice in the vent line so it closes more slowly than the letdown flow outside containment isolation valve. Manual control is also provided in the main control room and at the remote shutdown workstation.

6.3.3.15 Letdown Flow Outside Containment Isolation Valve

This normally closed, fail-closed, air-operated globe valve is located outside containment and isolates letdown to the liquid radwaste system. This valve automatically opens and closes on a plant control system signal from the pressurizer level control system or a containment isolation signal from the protection and safety monitoring system. This valve operates in the same fashion as the letdown flow inside containment isolation valve. The letdown flow outside containment isolation valve closes more quickly than inside containment letdown flow isolation valve to limit seat wear of inside containment isolation valve. This valve operator has a flow restricting orifice in the air line, so it opens more slowly than inside containment letdown flow isolation valve. In addition, during brief periods of shutdown, when the reactor coolant system is water solid, this valve throttles to maintain the reactor coolant system pressure. Manual control is also provided in the main control room and at the remote shutdown workstation.

6.3.3.16 Makeup Stop Valve

This normally open, air-operated stop-check valve is located inside containment and functions to isolate the flow in the charging line to the reactor coolant system. This valve can be closed from the main control room or the remote shutdown workstation to isolate charging downstream of the regenerative heat exchanger. This valve is closed to support the auxiliary spray function. The valve fails open on loss of power or loss of instrument air so the charging line to the reactor coolant system remains available.

6.3.3.17 Auxiliary Spray Line Isolation Valve

This normally closed, air-operated globe valve is located inside containment, downstream of the regenerative heat exchanger, and functions to isolate the auxiliary spray line to the reactor coolant system pressurizer. This valve is opened to provide flow to the auxiliary spray line during heatups and cooldowns to add chemicals or to collapse the steam bubble in the pressurizer. This valve fails closed on a loss of power or loss of instrument air to accomplish the function of preserving the reactor coolant pressure boundary. This valve closes automatically on a low-1 pressurizer level signal from the protection and safety monitoring system to preserve reactor coolant pressure boundary. This valve is operated from the main control room and the remote shutdown workstation.

6.3.3.18 Makeup Line Containment Isolation Valves

These normally open, motor-operated globe valves provide containment isolation of the chemical and volume control system makeup line and automatically close on a high-2 pressurizer level, high steam generator level, or high-2 containment radiation signal from the protection and safety monitoring system. The valves close on a source range flux doubling signal to terminate possible unplanned boron dilution events. The valves also close on a safeguards actuation signal coincident with high-1 pressurizer level. This allows the chemical and volume control system to continue providing reactor coolant system makeup flow, if the makeup pumps are operating following a safeguards actuation signal. These valves are also controlled by the reactor makeup control system and close when makeup to other systems is provided. Manual control is provided in the main control room and at the remote shutdown workstation.

6.3.3.19 Hydrogen Addition Containment Isolation Valve

This normally open, fail-closed, air-operated globe valve is located outside containment in the hydrogen addition line. The valve automatically closes on a containment isolation signal from the protection and safety monitoring system. Manual control is provided in the main control room and at the remote shutdown workstation.

6.3.3.20 Demineralized Water System Isolation Valves

These normally open, air-operated butterfly valves are located outside containment in the line from the demineralized water storage and transfer system. These valves close on a signal from the protection and safety monitoring system derived by either a reactor trip signal, a source range flux doubling signal, low input voltage (loss of ac power) to the 1E dc and uninterruptable power supply system battery chargers, or a safety injection signal, isolating the demineralized water source to prevent inadvertent boron dilution events. Manual control for these valves is provided from the main control room and at the remote shutdown workstation.

6.3.3.21 Makeup Pump Suction Header Valve

This air-operated, three-way valve is automatically controlled by the makeup control system to provide the desired boric acid concentration of makeup to the reactor coolant system (boric acid, demineralized water, or blend based on the desired reactor coolant system boron concentration). The valve fails with the pump suction aligned to the boric acid storage tank on a loss of instrument air. This valve also aligns to the boric acid storage tank on a reactor trip, source range flux doubling signal, low input voltage (loss of ac power) to the 1E dc and uninterruptable power supply system battery chargers, or safety injection signal from the protection and safety monitoring system. This valve also aligns the makeup pump suction to the boric acid storage tank when low pressure is detected in the demineralized water supply line to protect the pump from a loss of suction supply. Manual control for this valve is provided in the main control room and at the remote shutdown workstation.

6.3.3.22 Makeup Pump Suction Relief Valves

A relief valve is provided in the suction of each makeup pump to prevent overpressurization of the pump suction. These relief valves prevent overpressurization that might be caused by backleakage through the makeup pump discharge check valves when the pump suction valves are closed. The set pressure of these relief valves is equal to the pump suction design pressure. The relief capacity is sufficient to accommodate expected check valve back leakage rates.

6.3.3.23 Letdown Line Relief Valve

A relief valve is provided to prevent overpressurization of the letdown line connected to the waste processing system. This relief valve prevents overpressurization that might be caused by opening the letdown line with a closed valve in the waste processing system. The set pressure of this relief valve is equal to the design pressure of the line connecting to the waste processing system. The relief capacity is sufficient to accommodate a conservatively high letdown rate assuming minimum flow resistances in the piping, valves, orifices and equipment in the letdown line.

6.3.3.24 Resin Sluice Line Relief Valve

A relief valve is provided to prevent overpressurization of the line that is used to sluice resin from the mixed bed and cation bed demineralizers to the waste processing system. The set pressure of this relief valve is equal to the design pressure of the line it is connected to which is equal to the design pressure of the CVS purification equipment inside containment. The relief capacity is sufficient to accommodate thermal expansion of the water that is trapped between the two containment isolation valves that might occur following an accident that results in heatup of the containment.

6.3.4 System Operation

The operation of the chemical and volume control system for the various modes of reactor plant operation is described in the following subsections. Normal operating parameters for the chemical and volume control system are listed in Table 6.3-1.

6.3.4.1 Plant Startup

Plant startup is the operation that brings the reactor plant from a cold shutdown condition to no-load operating temperature and pressure, and subsequently to power operation.

The makeup pumps initially fill the reactor coolant system via the purification flow return line. During filling, makeup water is drawn from the demineralized water connection and blended with boric acid from the boric acid storage tank to provide makeup at the desired reactor coolant system boron concentration. The reactor coolant system is vented via the reactor vessel head and the pressurizer. A vacuum fill subsystem may be used to enhance the reactor coolant fill operation.

The auxiliary spray line may be used to fill the pressurizer and establish proper water chemistry in the pressurizer. If water solid operation is desired, reactor coolant system pressure is controlled by operation of the letdown control valve and the makeup control valve. To accomplish this, a letdown flow path is established to the liquid radwaste system with the letdown orifice bypassed.

The makeup flow rate is maintained by the makeup control valve at a constant value selected by the operators. At the same time, the letdown control valve controls letdown flow to maintain reactor coolant system pressure at a constant value, also selected by the operators. These water solid operations are not required if vacuum fill is used.

After the reactor coolant pumps are started, chemical treatment, using an oxygen scavenger, is performed. The oxygen scavenger is added to the reactor coolant during the initial stages of heatup to scavenge oxygen in the system. Subsequently, hydrogen makeup to the reactor coolant system is started, and the reactor coolant system hydrogen level is brought up to the normal operating point of approximately 30 cubic centimeters per kilogram.

The pressurizer heaters are used to heat up the water in the pressurizer and draw a steam bubble. As the steam bubble grows, effluent continues to be diverted to the liquid radwaste system through the chemical and volume control system letdown line. The makeup pumps are operated to supply demineralized water, so the reactor coolant system boron concentration is reduced to the level required for criticality. Following attainment of pressurizer normal water level, the letdown flow control valve and the makeup pumps are set to operate only as necessary to maintain pressurizer level or on demand from the operator.

6.3.4.2 Base-Load Operation

At a constant power level, the chemical and volume control system purification loop operates continuously as a closed loop around a reactor coolant pump. The purification flow is approximately 100 gallons per minute with one mixed-bed demineralizer and one reactor coolant filter in service. The chemical and volume control system makeup pumps and the letdown line to the liquid radwaste system are not normally operating. The makeup pumps are normally available and are set to start automatically on low pressurizer level. The boric acid blending valve in the pump suction permits the operator to preset the blend of boric acid and demineralized water to achieve the desired makeup concentration. The letdown control valve opens automatically, if the pressurizer level reaches its high (relative to programmed level) setpoint. Reactor coolant samples are taken to check boron and H_2 concentration, water quality, pH, and activity level.

Variations in power demand are accommodated automatically by control rod and gray rod movement. The only adjustments in boron concentration necessary are those to compensate for core burnup. These adjustments are made to maintain the rod control groups within their allowable limits by setting the makeup pumps to provide the required amount of demineralized water as makeup. If necessary, effluent is automatically routed to the liquid radwaste system to maintain the required pressurizer level.

6.3.4.3 Load-Follow Operation

Load-follow power changes and the resulting xenon changes are accommodated by the control rods and gray rods, with no changes required to the reactor coolant system boron concentration. The chemical and volume control system does not have load follow functions.

6.3.4.4 Plant Cooldown/Shutdown

If required for periods of maintenance or following spurious reactor trips, the reactor is maintained subcritical, with the capability to return to full power within the period of time required to withdraw the control rods. During hot standby operation, the average temperature is maintained at no-load $T_{av}g$ by initially dumping steam to the condenser to provide residual heat removal, or at later stages by running the reactor coolant pumps to maintain system temperature.

Initially the control rods are inserted and the core is maintained at or slightly above the minimum required shutdown margin. Following shutdown, xenon buildup occurs and increases the shutdown margin. The effect of xenon buildup increases the shutdown margin to a minimum of about 3 percent $\Delta k/k$ at about 9 hours following shutdown.

If rapid recovery is required, dilution of the system may be performed to counteract this xenon buildup. A shutdown group of rods is withdrawn during dilution to provide the capability for rapid shutdown if needed, and frequent checks are made on critical rod position.

Cold shutdown is the operation that brings the reactor plant from normal operating temperature and pressure to a cold shutdown temperature and pressure for maintenance or refueling.

The chemical and volume control system purification loop continues to operate normally in advance of a planned shutdown. In addition, in the beginning of a shutdown, the chemical and volume control system is designed so the letdown flow is routed out of containment to the liquid radwaste system, where it is stripped of gases and returned to the makeup pump suction. This gas stripping is required for approximately 48 hours to reduce reactor coolant activity level and hydrogen level sufficiently, permitting personnel access for refueling or maintenance operations.

Before cooldown and depressurization of the reactor coolant system is initiated, the reactor coolant boron concentration is increased to the cold shutdown value. The operator sets the reactor makeup control to "borate" and selects the volume of boric acid solution necessary to perform the boration. Correct concentration is verified by reactor coolant samples. The operator sets the reactor makeup control for makeup at the shutdown reactor coolant boron concentration.

Contraction of the coolant during cooldown of the reactor coolant system results in actuation of the pressurizer level control system to maintain normal pressurizer water level. Makeup continues to be automatic, with the makeup pumps starting and stopping as required.

During shutdowns, after the reactor coolant pumps are stopped, the normal residual heat removal system provides the motive force for chemical and volume control system purification loop. Whenever the reactor coolant system is pressurized, the chemical and volume control system can be operated to provide purification. After the normal residual heat removal system is placed in service and the reactor coolant pumps are stopped, further cooling and depressurization of the pressurizer fluids are accomplished by charging through the auxiliary spray connection.

6.3.4.5 Reactor Coolant System Leak

The chemical and volume control system is capable of making up for a small reactor coolant system leak with either makeup pump at reactor coolant system pressures above the low pressure setpoint.

6.3.4.6 Accident Operation

The chemical and volume control system can provide borated makeup to the reactor coolant system following accidents such as small loss-of-coolant accidents, steam generator tube rupture events, and small steam line breaks. In addition, pressurizer auxiliary spray can reduce reactor coolant system pressure during certain events such as a steam generator tube rupture.

To protect against steam generator overfill, the makeup function is isolated by closing the makeup line containment isolation valves, if a high steam generator level signal is generated. These valves also close and isolate the system on a high pressurizer level signal.

Some of the valves in the chemical and volume control system are required to operate under accident conditions to effect reactor coolant system pressure boundary and containment isolation.

6.3.4.7 Boron Dilution Events

The chemical and volume control system is designed to address a boron dilution accident by closing redundant safety-related valves, tripping the makeup pumps, and/or aligning the suction of the makeup pumps to the boric acid storage tank.

For dilution events occurring at power (assuming the operator takes no action), a reactor trip is initiated on either an overpower trip or an overtemperature ΔT trip. Following a reactor trip signal, the line from the demineralized water system is isolated via the closure of two safety-related, air-operated valves. The three-way pump suction control valve aligns so that the makeup pumps take suction from the boric acid storage tank. If the event occurs while the makeup pumps are operating, the realignment of these valves causes the makeup pumps, if they continue to operate, to borate the plant.

For dilution events during shutdown, the source range flux doubling signal causes (1) isolation of the makeup line to the reactor coolant system via closure of two safety-related, motor-operated valves, (2) isolation of the line from the demineralized water system via closure of two safety-related, air-operated valves, and (3) trips of the makeup pumps. For refueling operations, administrative controls are used to prevent boron dilutions by verifying the valves in the line from the demineralized water system are closed and secured.

Table 6.3-1

NOMINAL CHEMICAL AND VOLUME CONTROL SYSTEM PARAMETERS

Purification flow rate (gpm)	100[a]
Normal boration flow rate (gpm)	100
Normal dilution flow rate (gpm)	100
Temperature of reactor coolant entering chemical and volume control system (assumed) (°F)	537
Expected life of demineralizer resin	1 fuel cycle
Normal temperature of effluent to liquid radwaste system (°F)	130
Flow rate to liquid radwaste system (gpm)	100

Note:

a. Volumetric flow rates are based on 130°F and 2300 psia.

Table 6.3-2 (Sheet 1 of 3)

CHEMICAL AND VOLUME CONTROL SYSTEM NOMINAL EQUIPMENT DESIGN PARAMETERS

Pumps		
Makeup Pumps		
Number	2	
Type	Multistage horizontal centrifugal	
Design pressure (psig)	3,100	
Design flow (gpm)	140	
Material	Stainless Steel (SS)	
Heat Exchangers		
Regenerative Heat Exchanger		
Number	1	
Type	Counterflow	
	Shell Side	**Tube Side**
Design pressure (psig)	3,100	3,100
Design temperature (°F)	600	650
Design flow (lb/hr)	41,580	49,710
Material	SS	SS
Letdown Heat Exchanger		
Number	1	
Type	U-Tube	
	Shell Side	**Tube Side**
Design pressure (psig)	150	3,100
Design temperature (°F)	150	600
Design flow (lb/hr)	224,034	49,710
Material	Carbon Steel	SS

Table 6.3-2 (Sheet 2 of 3)

CHEMICAL AND VOLUME CONTROL SYSTEM
NOMINAL EQUIPMENT DESIGN PARAMETERS

Demineralizers	
Mixed Bed Demineralizer	
Number	2
Design pressure (psig)	3,100
Design temperature (°F)	200
Design flow (gpm)	250
Resin volume (ft^3)	50
Material	SS
Resin type	Mixed Bed Li7OH Form
Cation Bed Demineralizer	
Number	1
Design pressure (psig)	3,100
Design temperature (°F)	200
Design flow (gpm)	250
Resin volume (ft^3)	50
Material	SS
Resin type	Cation H+ Form

Table 6.3-2 (Sheet 3 of 3)

CHEMICAL AND VOLUME CONTROL SYSTEM NOMINAL EQUIPMENT DESIGN PARAMETERS

Filter	
Reactor Coolant Filter	
Number	2
Type	Disposable Cartridge
Design pressure (psig)	3,100
Design temperature (°F)	200
Design flow (gpm)	250
Dp at design flow (psi)	10
Tank	
Boric Acid Tank	
Number	1
Volume (gal)	73,515
Type	Cylindrical
Design pressure (psig)	Atmospheric
Design temperature (°F)	200
Material	SS