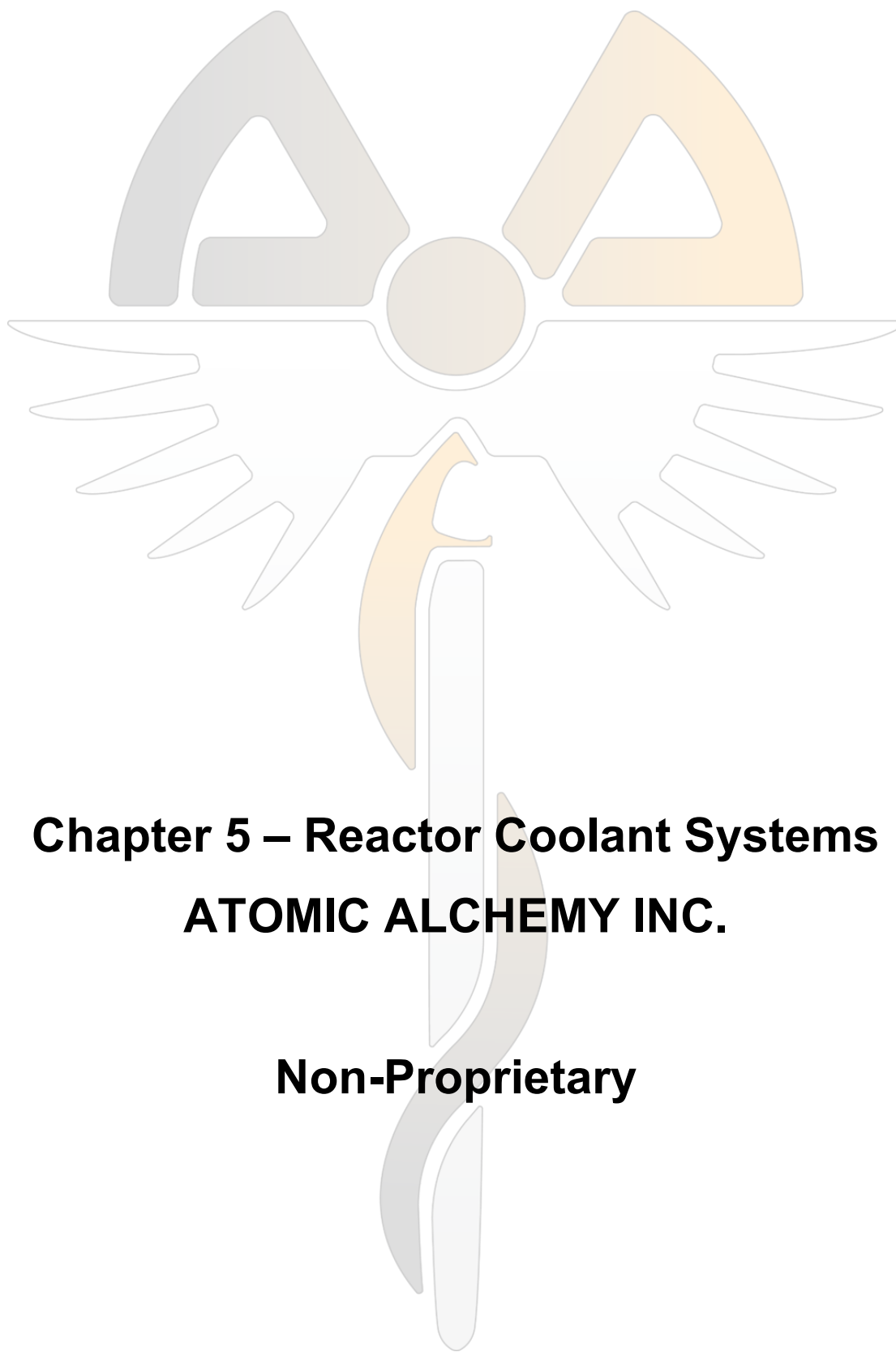




Chapter 5 – Reactor Coolant Systems

ATOMIC ALCHEMY INC.

Non-Proprietary

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TERMS

ACRONYMS AND ABBREVIATIONS

Common acronyms, abbreviations, and units of measurements may not be included here as it is assumed the reader is familiar with their meaning.

AAI	Atomic Alchemy Inc.
DANK	deuterium-augmented nuclear kinetics
PCP	primary coolant pump
PCS	primary coolant system
RCS	reactor coolant system
SCS	secondary coolant system
VIPR	Versatile Isotope Production Reactor
WPS	water purification and storage system



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5 REACTOR COOLANT SYSTEMS

5.0 INTRODUCTION

This section describes the Atomic Alchemy (AAI) reactor coolant systems. Each Versatile Isotope Production Reactor (VIPR) in the AAI Meitner-1 Facility will have dedicated reactor coolant systems. This section details all systems that are involved in maintaining reactor cooling capability for safe operation and shutdown of the reactor under all credible operating conditions.

This chapter, along with the information presented in Chapter 4 and Chapter 13, demonstrates that there are sufficient systems in place to ensure adequate cooling of the VIPR core for all design basis events.

The values presented in this chapter refer to the analytical limits established in Chapter 4 and Chapter 14, Appendix A.

5.1 SUMMARY DESCRIPTION

The reactor coolant system (RCS) is designed to remove up to 16.8 MW of thermal power by means of forced convection during steady state operation and up to 500 kW of thermal power by natural convection during shutdown. Full power operation requires forced convection to effectively remove the heat generated. Natural circulation is effective at removing the decay heat from the core. Chapter 4, Section 6, “Thermal-Hydraulic Design” details the RELAP modeling and calculations methodology of the forced convection and natural circulation heat removal.

The RCS for each VIPR core is made up of a primary coolant system (PCS) and a secondary coolant system (SCS). The RCS is used to remove the heat generated from the VIPR core, which is ultimately vented to the atmosphere as shown in **Figure 5-1**. The RCS piping is designed to contain the coolant under all anticipated temperatures and pressures and limits coolant leakage (and any potential radioactivity release) to the atmospheres of the confinement.



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Figure 5-1: The primary and secondary cooling loops for the VIPR core

Water leaves the pool via a primary coolant pump (PCP), travels through a shell and tube heat exchanger, and returns to the pool after passing through the VIPR core. The heat exchange transfers the heat from the PCS to the SCS. The SCS removes the heat from the system using a cooling tower.



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The PCS operates as the primary system within the RCS, circulating demineralized water upward through the VIPR core in an open-loop configuration, as shown in **Figure 5-2**.

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Figure 5-2: Thermal and fluid overview of the PCS in relation to the reactor pool and the VIPR core

The PCS is designed with additional systems to support its operation: the water purification and storage system (WPS), the cleanup system, and the N-16 suppression system. Support systems do not contribute to core heat removal but contribute to maintaining the operational integrity and functionality of the PCS. The WPS will be connected to the pool's height detection instrumentation and will ensure the pool water level is maintained during all operating conditions. The pool makeup water in the WPS is designed to replace water lost from evaporation, spills, or leaks in the PCS. The cleanup system is designed to maintain the purity of the coolant by continuously filtering and demineralizing the water in the PCS. An N-16 suppression system is designed to prevent harmful levels of N-16 from rising to the surface of the pool.

The deuterium-augmented nuclear kinetics (DANK) tank is a heavy water tank with [] ^{PROP,ECI} positions that will hold experiments during the operation of the reactor. The DANK tank will be constructed with aluminum. All other material used in the PCS will consist of 304 stainless steel, 316 stainless steel, 304L stainless steel, 316L stainless steel, or alloy 690. The connection between the DANK tank and other components in the PCS will consist of mating dissimilar metals together. These



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connection points will use specialized fittings to eliminate the galvanizing effects. The piping standard used in the reactor coolant system is Schedule S-40. The pool structure is a combination of concrete and high-density barytes concrete.

Components of the reactor coolant systems will be fabricated in accordance with applicable codes and standards that align with their designated functions and reflect their importance to system integrity. There are no safety-related components in the primary or secondary coolant systems. To support the reliable performance of the PCS, dedicated procedures will be implemented to address the following:

- Instrumentation, alarms, alerts, and mechanical components will be periodically tested, inspected, and calibrated in accordance with applicable standards and regulatory expectations, based on their function.
- Leak surveillance will be conducted to enable early detection of any significant loss of primary coolant.
- Primary coolant will be periodically sampled to identify the presence of radioactive impurities.
- Pressure differentials, flow rates, and water purity will be monitored to assess the need for replacement of purification system components.
- Strainers will be routinely examined for large particulates indicative of corrosion.
- Components of the primary coolant system, including the pool liner, will be inspected on a regular basis for evidence of corrosion and leakage.



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5.2 PRIMARY COOLANT SYSTEM

5.2.1 Overview

Cooling of the VIPR core is achieved by forced convection in steady state operation and natural convection in shutdown and loss of power conditions. As discussed in Chapter 4 and Chapter 13, the forced and natural convection modes are sufficient to keep the reactor cooled in both steady state and accident conditions.

The PCS coolant loop is composed of the pool, pool liner, pump, and the heat exchanger which passes heat to the SCS. The core is actively cooled by subcooled water flowing up through the core and into the reactor pool. Primary coolant is cycled from the pool into a shell and tube heat exchanger by the PCP as shown in **Figure 5-3**. The reactor and plenum are placed inside the pool as indicated by the dashed line in **Figure 5-3**.

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Figure 5-3: Primary coolant system overview

The location of the piping of the PCS and the design of the reactor pool ensures that the VIPR core will always be covered by water. The primary bay, which contains the PCP, heat exchanger, and piping for the PCS, is designed such that a break in the main pipeline would cause water from the pool to fill the primary bay and equalize at no less than 2 m above the VIPR core. There is almost 3 m between the top of the VIPR core and the floor of the primary bay with a pit for the pipe routing and an access area as deep as the floor of the reactor pool as shown in **Figure 5-4**. In the event of a major pipe break in the primary coolant loop, the water would equalize between the reactor pool and the primary bay.



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Figure 5-4: The reactor pool and primary bay design and dimensions (m)



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5.2.2 Design Basis

The design basis and functional requirements of the PCS are as follows:

- The PCS transfers up to 16.8 MW of thermal power during steady state operation to the SCS.
- The PCS provides the water that's used as the primary neutron moderator and reflector conserving thermal neutrons and improving neutron economy.
- The PCS boundary accommodates the temperatures and pressures associated with operating conditions and all postulated accidents.
- The PCS supplies the coolant flow necessary to maintain the minimal cooling capacity of the VIPR core for steady state operation.
- The PCS heat exchanger tubes and tubesheet boundary prevent the transfer of potential radioactivity generated within the core to the SCS.

The design basis of the PCS is derived from the operating parameters established in Chapter 4 to ensure sufficient cooling capability of the core and Chapter 13 on postulated accidents. **Table 5-1** details the operating parameters for the reactor power, fluid flow rates, VIPR core pressure and temperatures, and minimal water height above the core.

Table 5-1: Primary coolant operating range for steady state conditions

	Nominal	Minimal	Maximum
Reactor Power	15 MW	N/A	16.8 MW
Coolant Mass Flow Rate	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Pressure, Core Inlet	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Pressure, Core Outlet	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Coolant Temperature, Inlet	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Coolant Temperature, Outlet	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Coolant Temperature, Pool	[] ^{PROP}	[] ^{PROP}	[] ^{PROP}
Water Height Above the Core	[] ^{PROP,ECI}	[] ^{PROP,ECI}	[] ^{PROP,ECI}

The pressure in the system is estimated with current design parameters. This section will be developed further in the FSAR once the final design has confirmed pipe lengths, pump operating parameters, heat exchanger sizing, and friction losses in the PCS.

The primary coolant system boundary provides a physical barrier against the potential release of radioactivity generated within the VIPR core and spent fuel that may be transported throughout the reactor coolant system.



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5.2.3 Primary Coolant System Components

5.2.3.1 Reactor Pool

The reactor pool is composed of a 304L stainless steel pool that is further supported on the outside of the pool with stiffener rings. The pool shape, dimensions, and layout are depicted in **Figure 5-4**. The pool size and depth are design bases that ensure natural convection will be established and sufficient radiation shielding is provided to prevent excessive radiation exposure. The pool is watertight to prevent water leakage from the pool.

The design of the reactor pool ensures that the VIPR core is as low as possible in the pool. This is done to ensure the VIPR core is covered by a minimum of 2 m of water in the event of a large break loss of coolant accident. In this event the water in the reactor pool is drained into the primary bay and will equalize several meters above the VIPR core and ensure its safety. A detailed analysis of this event is analyzed in Chapter 13.

5.2.3.1.1 Shielding

The pool water depth provides shielding from the reactor at the top of the pool while the high-density barytes concrete ensures sufficient shielding from the reactor core, as described in Chapter 4. From a shielding perspective, []^{SEC,ECl} of ordinary concrete or []^{SEC,ECl} of barytes concrete is needed around the pool to ensure proper shielding. **Figure 5-4** depicts the pool with the minimal []^{SEC,ECl} of ordinary concrete. Further studies in the FSAR will be done once the final design has determined the placement and materials used for the concrete structure to ensure structural integrity of the pool for the life of the VIPR reactor.

Under normal operations the nominal value of the water height is []^{PROP,ECl} above the core while the conservative value of []^{PROP,ECl} of water above the core was used in calculations to minimize the radiation exposure rate to personnel at the top of the core. The full analysis of the minimal dimensions needed for shielding is described in Chapter 4.



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5.2.3.2 Plenum

The flow parameters from the PCS that actively cool the VIPR core are shown in **Table 5-1**. The fuel elements are located at the outlet of the plenum within the DANK tank. Water from the heat exchanger is evenly distributed across the VIPR core via the reactor plenum. Built-in passive inlet ports on each edge of the plenum allow water from the reactor pool to circulate through the VIPR core via natural convection when forced flow through the PCS stops. This passive circulation is driven by the temperature difference between the reactor pool and the decay heat generated by the core. Cooling required for the experiments will be provided through the passive circulation of the pool water and is discussed further in Chapter 10. Flow paths through the plenum for both forced and natural convection conditions are shown in **Figure 5-5**.

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Figure 5-5: Forced flow path and passive flow path, rotated 90 degrees



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The coolant ejected from the plenum will flow through all []^{PROP,ECI} fuel assemblies and the center reflector as shown by the primary coolant flow boundary in **Figure 5-6**. The flow distribution within the VIPR core is primarily handled by the shortened []^{PROP,ECI} fuel assemblies that uses []^{PROP,ECI} and []^{PROP,ECI} spacer grids to enhance the mixing within the fuel assemblies. The fuel assemblies are open on the sides to allow mixing of the coolant between assemblies.

[]^{PROP,ECI}

Figure 5-6: Reactor cross section to show the primary coolant flow boundary

The primary function of the VIPR's core plenum is to create an optimized flow distribution of the coolant into the core and the center reflector. The final design of the plenum will determine the flow distribution into the VIPR core. This analysis will determine if the plenum needs an orifice plate to distribute the flow properly. The spacing between the fuel assemblies and reflector and the need for an orifice plate will be determined for the FSAR.

5.2.3.3 Heat exchanger

The heat exchanger is a vertical-shell U-tube type. On the heat exchanger shell side, the primary coolant flow enters the elliptical chamber head. The other half of this elliptical head is provided with a



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single discharge nozzle. On the secondary side, a double pass counterflow is provided on the tube side; one nozzle each is provided for supply and return water from the SCS. This arrangement provides enhanced access to all tubes, including those at the periphery of the bundle.

Under normal operating conditions, there are no radioactive contaminants present in the water contained in the secondary side of the heat exchanger. The design of the heat exchanger maintains higher pressure in the SCS to ensure that any leak in the heat exchanger will add water to the PCS side. Radiological monitoring of the PCS and SCS will be provided with specific SSCs in the FSAR.

5.2.3.4 Pump

The flow through the PCS is powered by a single primary pump. The pump motor is driven by a variable frequency drive. The variable frequency drive enables the pump to start at low speeds.

5.2.3.5 Piping

The PCS intake from the reactor pool is located 2.85 m above the top of the VIPR core as seen in **Figure 5-4**. The piping intake from the pool location is connected to a gate isolation valve and a check valve. There is a replaceable strainer provided on the inlet to this opening to ensure no large particles are passed through the pump or heat exchanger to minimize fouling. The piping is a 16-inch schedule 40 pipe.

The PCP discharges through an isolation valve into the PCS heat exchanger hemispherical head using a 14-inch schedule 40 pipe. A single discharge header from the heat exchanger flows through a 14-inch schedule 40 pipe into the pit of the primary bay and passes through a check valve and continues along the bottom of the reactor pool also using a 14-inch schedule 40 pipe. The pipe connects to the plenum that is located below the reactor. The coolant flows up through the plenum and the core, **Figure 5-5**, into the other end of the pool to mix with the bulk coolant before entering again the PCS intake.

All piping will be coated or treated to minimize corrosion. The piping embedded into the pool structure will be radiographed and dye penetration tested. Pipe connections will be either welded or flanged to components that will need to be serviced or replaced throughout the lifetime of the reactor. This section will be further developed with specific details in the FSAR.

5.2.4 Instrumentation

The location of the instruments that monitor the operation of the PCS is shown in **Figure 5-3**. The operating limits established in the design criteria are monitored by different instruments to ensure the cooling of the core. Values for coolant pH and conductivity are given in Section 5.4. The alarm setpoint and trip setpoint are determined by the limiting safety system settings defined in the design criteria of the PCS.

The PCS uses the following instrumentation to monitor the coolant conditions.

TT – Temperature

The temperature of the coolant is measured in various locations in the PCS. The temperature will be monitored in the following locations:



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- reactor pool
- pump discharge
- heat exchanger inlet nozzle
- heat exchanger outlet
- reactor inlet

PT – Pressure

The pressure will be measured in the system to ensure no flow restrictions will occur in the PCS. The following locations will have pressure sensors:

- pump inlet
- pump discharge
- heat exchange inlet nozzle
- heat exchanger outlet

FT - Flow Rate

The flow rate is measured in the piping of the PCS through a pressure differential sensor. There are flow rates sensors in the following locations within the system:

- pump discharge
- heat exchanger outlet
- reactor inlet

LT - Pool Water Level

There are high and low pool water level alarms that notify operators when the pool level is outside nominal water level height.

CT- Conductivity

The water conductivity is measured to ensure the quality of water is treated to prevent corrosion or damage to the PCS.

Radioactivity

The levels of radioactivity in the water will be monitored including N-16, Ar-41, and H-3 to prevent airborne doses exceeding operational or public dose limits.

5.2.5 Leak detection

Leak detection monitoring is accomplished using instrumentation and diverse measurement parameters such as pool water height, flow, and detection of radioactivity. PCS piping boundary leakage detection monitoring provides a means of detecting and, to the extent practical, identifying the source and quantifying the volume of primary coolant leakage. The leak detection system will be employed over the piping, heat exchanger, DANK tank, and reactor pool. The FSAR will have full details on the leak detection programs for the following areas:

- Primary Coolant Pipe Leak Detection
- Heat Exchanger Leak Detection



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- DANK Tank Leak Detection
- Reactor Pool Leak Detection

5.2.6 Radiation concentration limits (sampling frequency, isotopes, actions)

Impurities and radioactivity will be sampled periodically in the PCS. Samples will be taken from either the reactor pool or the cleanup system to test for the presence of fission products and their concentration. The frequency of sampling, limits on the concentration of specific isotopes, and the required action will be described in the FSAR.

5.3 SECONDARY COOLANT SYSTEM

5.3.1 Secondary Coolant System

The SCS removes heat from the PCS. The SCS consists of the heat exchanger which removes heat from the PCS, one pump, a surge tank, a chemistry-control system, a makeup water system, and a cooling tower as shown **Figure 5-7**.

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Figure 5-7: Secondary Coolant System



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The SCS components are all located in the mechanical hall. Heat is removed from the secondary system by a cooling tower designed to remove up to 16.8 MW of thermal power. Water is cycled between the PCS heat exchanger and the cooling tower by the secondary pump. The SCS pump is a centrifugal pump operating at an elevated pressure relative to the PCS to ensure that no primary coolant leaks into the SCS. The cooling tower is dependent on environmental factors to effectively remove heat from the SCS. The highest wet bulb temperature recorded from local meteorological data (found in Chapter 2) will be used to ensure sufficient cooling capacity of the cooling tower. The freezing temperatures are considered for components that are located outside of the Meitner-1 facility. Appropriate measures will be taken to ensure proper function of all components outside exposed to freezing temperatures.

The temperature, flow rates, and pressure will be monitored in the SCS to ensure the performance of the cooling tower. The SCS will be fitted with a surge tank to accommodate volume fluctuations due to temperature changes and ensure sufficient water is maintained in the closed loop system. The SCS has a dedicated chemistry-control system. The chemistry-control system is designed to minimize corrosion by controlling the water purity according to manufacture requirements for the cooling tower.

The SCS will cease operation when the PCS is shut down for a planned or accident event. This will ensure the secondary coolant temperatures will not lower the PCS water temperature below the operating threshold.

The FSAR will include details about the secondary system flowrate, the location of the system in relation to the reactor, the inlet and outlet temperatures, the system pressure, the materials and fabrication specifications, and other pertinent SCS specifications.

5.4 PRIMARY COOLANT CLEANUP SYSTEM

The cleanup system, of the PCS, takes on the function of the primary coolant cleanup system and controls the chemistry balance and purity of the primary coolant for all steady state conditions. The cleanup system does not perform any function important to safety, and each reactor system will have its own cleanup system. The used fuel pool also has its own dedicated cleanup system described in Chapter 9, Section 9.7.3. The cleanup system is designed to prevent corrosion of any surfaces in contact with the primary coolant. The purity of the water will be monitored in the reactor pool. The design basis of this system is to ensure that the water purity is within the NUREG-1537 recommended range:

- Electric conductivity $\leq 5 \mu\text{S}/\text{cm}$
- Potential hydrogen (pH) between 5.5 and 7.5



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This will be accomplished by a pipe running water from the top of the reactor pool into a series of micron filters and a demineralizer mixed bed resin column as seen in **Figure 5-8**. The filters and demineralizer resin tank will be sized to allow a wide range of flow rates through the system.

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Figure 5-8: Primary coolant cleanup system

The sizing of the filters will be selected in accordance with the manufacture recommendation of 1 to 25 micrometers. The demineralizer resin tank will be sized to allow a wide range of flow rates through the system to ensure the design basis of the water purity is maintained.

The cleanup system is in the reactor confinement module of the facility adjacent to the reactor pool. The system uses stainless steel piping to draw water from the top of the pool at a flow rate between 8 and 30 m³/h. The water is passed through a gate valve into a strainer to a single stage centrifugal pump. The pump discharges into a micron filter and into the demineralizing resin tank. The tank's discharge water is passed through a second filter and returned to the top of the reactor pool.

The resin tank has separate flanged connections for the replacement or recharging of the resin. The replacement of the filter and resin will be done in a manner commensurate with their importance to safety and the potential exposure to radiation from radioactive material buildup in the demineralizer. Procedural steps are taken to limit the radiation exposure when changing the filters and resin. The used resin and filters are managed as radioactive waste.



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5.5 PRIMARY COOLANT MAKEUP WATER SYSTEM

The WPS takes on the function of the primary coolant makeup water system and is designed to replace water that is lost from evaporation or small leaks in the reactor pools or the PCS during normal operation. The WPS is not required for safe shutdown and performs non-safety water makeup for all steady state conditions. The used fuel pool also has its own dedicated WPS described in Chapter 9, Section 9.7.2. The WPS takes water from a storage tank and passes it through a reverse osmosis filtration system. A separate storage tank is used for the purified water and is available to the different PCSs or reactor pools as needed. The reverse osmosis water storage tank is connected to the cleanup system that will further filter and demineralize the water that enters the PCS as seen in **Figure 5-8** and **Figure 5-9**.

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Figure 5-9: Make-up water system

The conductivity of the reverse osmosis water storage tank is constantly measured to ensure that the reverse osmosis process is functioning correctly. The WPS is only connected to the cleanup system when the pool water needs to be added within the low pool limit set points. The FSAR will specify how many reactor pools and reactor coolant systems may be serviced with a single WPS and if the system will provide service to the used fuel pool and coolant system.

5.6 NITROGEN-16 SUPPRESSION SYSTEM

The upward flow of the primary coolant towards the top of the pool creates a concern of N-16 exposure to personnel around or at the pool surface. The dose rate of the radiation at the surface of the pool is dependent on a combination of the pool water height above the core, the flow rate coming out of the core, the mixing of the coolant with the bulk fluid and the N-16 half-life. The low flow velocity out of the core mixing into the bulk fluid delays the rise of N-16 to the surface of the pool. To ensure the safety limits of exposure to N-16, a suppression system will be designed to delay the flow from the core outlet to the surface of the pool. The flow loop will take water from the pool surface into a single-phase pump and force the same water back into the pool above the core. The design of the system delays the water exiting the VIPR core from reaching the pool surface by disturbing the coolant leaving the core as shown in **Figure 5-10**. The final specification of the N-16 suppression system will be specified in the FSAR.



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Figure 5-10: N-16 Suppression system line diagram

5.7 AUXILIARY SYSTEMS USING PRIMARY COOLANT

There are no additional systems that the primary coolant system requires to perform its function to maintain the safe operation of the core in any condition. All auxiliary systems that interface with primary coolant or the facility will be detailed in Chapter 9. All auxiliary systems are designed to ensure that there is minimal impact of the reactor coolant temperature and coolant water level. The auxiliary systems do not prevent sufficient coolant to be available to cool the VIPR core.

5.8 REFERENCES

Nuclear Regulatory Commission. 1996. NUREG-1537, Part 1, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content.”