CHAPTER 5

COOLING SYSTEMS

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
μmho/cm	micromho per centimeter
ALARA	as low as reasonably achievable
Ar-41	argon-41
ASME	American Society of Mechanical Engineers
Btu	British thermal unit
Btu/hr	British thermal units per hour
cm	centimeter
DBT	dry bulb temperature
FCHS	facility chilled water system
FCRS	facility chemical reagent system
FDWS	facility demineralized water system
FNHS	facility nitrogen handling system
FPWS	facility potable water system
FSTR	facility structure
FVZ4	facility ventilation zone 4
gpm	gallons per minute

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
hr	hour
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
ICBS	irradiation cell biological shield
IF	irradiation facility
IU	irradiation unit
kW	kilowatt
LABS	quality control and analytical laboratories
LWPS	light water pool system
MCWB	mean coincident wet bulb temperature
MEPS	molybdenum extraction and purification system
MM	million
N-16	nitrogen-16
NDAS	neutron driver assembly system
NPSS	normal electrical power supply system

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
PCLS	primary closed loop cooling system
PCHS	process chilled water system
PICS	process integrated control system
PSB	primary system boundary
psi	pounds per square inch
PVVS	process vessel vent system
RCA	radiologically controlled area
RO	reverse osmosis
RPCS	radioisotope process facility cooling system
RVZ1	radiological ventilation zone 1
RVZ1e	radiological ventilation zone 1 exhaust subsystem
RVZ1r	radiological ventilation zone 1 recirculating cooling subsystem
RVZ2	radiological ventilation zone 2
RVZ2r	radiological ventilation zone 2 recirculating cooling subsystem

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	**Definition**
SASS	subcritical assembly support structure
SCAS	subcritical assembly system
sccm	standard cubic centimeters per minute
scfh	standard cubic feet per hour
scfm	standard cubic feet per minute
slpm	standard liters per minute
SRWP	solid radioactive waste processing
TOGS	TSV off-gas system
TRPS	TSV reactivity protection system
TSPS	target solution preparation system
TSV	target solution vessel
UPSS	uninterruptible electrical power supply system
WBT	wet bulb temperature

5a2 IRRADIATION FACILITY COOLING SYSTEMS

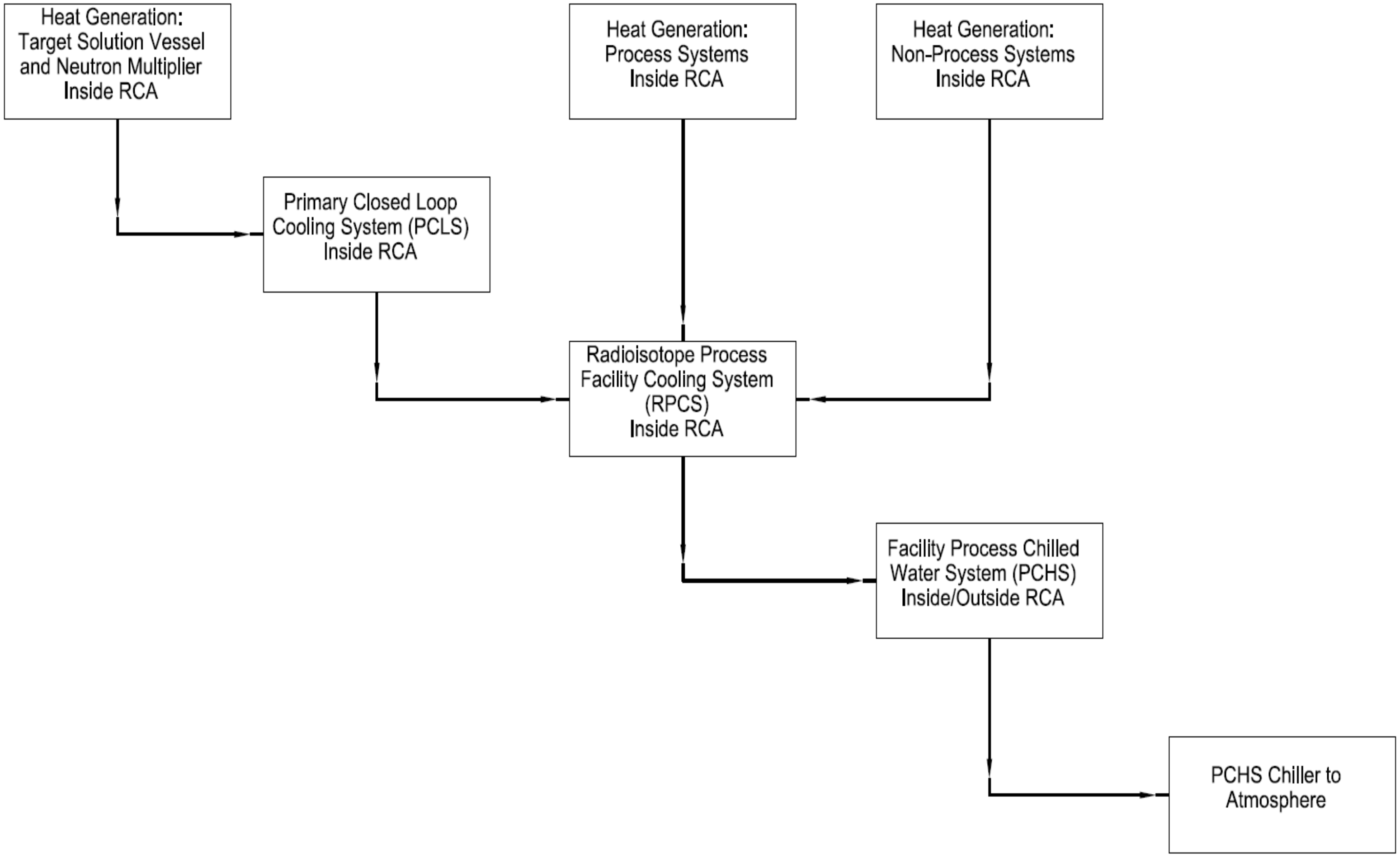
5a2.1 SUMMARY DESCRIPTION

The purpose of the irradiation facility (IF) cooling systems is to safely remove the fission and decay heat from the target solution and dissipate it to the environment. The primary closed loop cooling system (PCLS) removes heat from the subcritical assembly. The light water pool provides passive heat removal for the subcritical assembly and is described in detail in Section 4a2.4. The radioisotope process facility cooling system (RPCS) is the secondary cooling system for the facility. See Chapter 13 for a discussion of accident scenarios.

The target solution vessel (TSV) and neutron multiplier within each IU are cooled by the PCLS while the IU is in operation. The PCLS is a closed loop chilled water system that rejects heat to the RPCS, an intermediate chilled water loop, which rejects heat to the process chilled water system (PCHS). The PCHS is a closed chilled loop that rejects heat to the atmosphere by use of air-cooled chillers. Figure 5a2.1-1 depicts the heat flow path from generation to the environment. The neutron driver cooling is addressed in Section 4a2.3 and the recirculating heating, ventilation, and air conditioning (HVAC) fan-coil unit that is part of the radiological ventilation zone 1 recirculating cooling subsystem (RVZ1r) is discussed in Section 9a2.1.

The primary and secondary IF cooling systems maintain the capability to provide sufficient heat removal to support continuous operation at full licensed power as discussed in the subsequent sections.

Figure 5a2.1-1 – Cooling Systems Heat Flow Pathway Diagram



5a2.2 PRIMARY CLOSED LOOP COOLING SYSTEM

5a2.2.1 DESIGN BASES AND FUNCTIONAL REQUIREMENTS

The primary closed loop cooling system (PCLS) provides forced convection water cooling to the target solution vessel (TSV) and neutron multiplier during irradiation of the target solution and immediately prior to transferring target solution from the TSV to the TSV dump tank. The PCLS also provides indirect cooling of the light water pool via natural convection heat transfer to the PCLS components submerged in the pool, as described in Subsection 4a2.7.3. The PCLS rejects heat to the radioisotope process facility cooling system (RPCS). A total of eight independent instances of PCLS are installed in the irradiation facility (IF), one for each irradiation unit (IU). There are no common pressure retaining components between the instances of PCLS. The major PCLS equipment is located in the primary cooling room and the IU cell.

Each instance of PCLS includes two pumps, a heat exchanger, and a cooling water clean-up side stream located in the primary cooling rooms adjacent to the east side of each IU cell. In the IU cell, the PCLS is connected to the subcritical assembly system (SCAS) and includes an air separator, an expansion tank, and a nitrogen-16 (N-16) delay tank. Figure 5a2.2-1 provides a PCLS flow diagram.

The process functions of the PCLS cooling system are to:

- remove heat from each TSV and neutron multiplier during full-power IU operation;
- cool the light water pool by natural convection heat transfer to PCLS components inside the light water pool;
- maintain water quality to reduce corrosion and scaling;
- limit concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation;
- reduce N-16 radiation exposure within the primary cooling room in support of as low as reasonably achievable (ALARA) goals; and
- remove entrained gases from the cooling water.

PCLS removes heat from the TSV and neutron multiplier during startup and irradiation by circulating water in an upward direction [
]$^{\text{PROP/ECI}}$ along the exterior surfaces of the TSV and neutron multiplier walls. The subcritical assembly support structure (SASS) provides the shell side pressure boundary to direct the cooling water flow past the TSV and neutron multiplier. The PCLS is attached to the SASS upper and lower plenums.

PCLS is designed to remove a minimum of 580,000 British thermal units per hour (Btu/hr) (170 kilowatts [kW]) of heat from each IU during full-power operation and during shutdown conditions when target solution is in the TSV.

PCLS is designed to maintain the pressure of the cooling water in the SASS higher than the internal pressure of the TSV. The TSV is designed and fabricated to prevent target solution from leaking into the PCLS. See Section 4a2.4 for additional information related to the TSV.

The PCLS cleanup side stream maintains system cooling water quality. The PCLS is designed to operate without corrosion inhibiting chemicals in the process fluid. The cleanup side stream can divert a portion of the PCLS flow to continuously remove particulates and ions from the cooling water. See Section 5a2.5 for additional information related to the PCLS cleanup side stream.

The PCLS piping confines the cooling water within the IU cell and within the primary cooling room located adjacent to the IU cell. Pressure retaining components are constructed of materials that effectively resist corrosion to limit activation products that could cause increased radiation exposure of personnel and surrounding equipment. Major components are constructed of austenitic stainless steel.

The PCLS air separator separates entrained gases from the cooling water and directs the gases to the radiological ventilation zone 1 exhaust (RVZ1e) subsystem via the PCLS expansion tank.

N-16 is generated in the cooling water by the neutron activation of oxygen. Section 5a2.7 provides a discussion of the treatment of N-16 in the cooling water.

Overpressure protection for PCLS is provided by system design. The shutoff head of the PCLS pumps is below the PCLS design pressure. The PCLS is also directly vented to RVZ1e through the PCLS expansion tank.

See Table 5a2.2-1 for the PCLS operating parameters. See Table 5a2.2-2 for a list of the PCLS components.

5a2.2.2 PCLS ANALYSES

Detailed analysis of the PCLS target solution cooling performance is found in Section 4a2.7. Heat transfer and temperature profiles for the neutron multiplier are found in Subsection 4a2.2.6.

If active cooling to the TSV and neutron multiplier is unavailable, irradiation of the target solution will be suspended. Target solution in the TSV will be transferred from the TSV to the TSV dump tank, which is passively cooled by the light water pool. See Subsection 4a2.4.2.2 for the heat removal capacity of the light water pool. Loss of cooling design basis accidents are discussed in Subsection 13a2.1.3.

Two PCLS pumps operate in parallel to provide the design flowrate to the PCLS heat exchanger. Should one pump fail, the second pump, operating at a minimum of [ ]$^{\text{PROP/ECI}}$, provides adequate cooling to allow continuation of full-power irradiation while maintaining the bulk target solution temperature less than 176°F (80°C) within the TSV.

The light water pool and TSV are located within the primary confinement, which also provides confinement of the components of the PCLS located within the IU cell, as discussed in Section 6a2.2. The PCLS piping penetrations through primary confinement are located above the minimum acceptable water level in the pool.

Shielding to protect workers and reduce dose rates to equipment is provided by the irradiation cell biological shield (ICBS), described in detail in Section 4a2.5.

Effects resulting from a primary cooling water breach are discussed in Subsection 4a2.7.3.7. Loss of primary cooling water does not result in loss of integrity of the primary system boundary (PSB). Low cooling water flow causes an IU Cell Safety Actuation, which results in the TSV dump valves opening and the target solution draining to the TSV dump tank. The thermal mass of the target solution prevents boiling of the solution during the draining process. Once the target solution has drained to the TSV dump tank, the light water pool prevents the solution from boiling by natural convection heat transfer. See Subsection 4a2.7.3.8 for further discussion on the transition from forced to natural convection.

Voiding of the SCAS cooling channels caused by loss of primary cooling water causes reactivity insertions as discussed in Subsection 13a2.1.2. To prevent the drainage of primary cooling water from the SCAS, the SCAS is located below grade in the light water pool. Portions of the PCLS located outside of the light water pool are above grade to prevent gravity drainage of the SCAS cooling channels.

The PCLS pumps draw cooling water from a line connected to the PCLS expansion tank. Because the expansion tank is vented, a leak of the PCLS pressure boundary would result in the PCLS expansion tank level reducing until the PCLS return line breaks vacuum. Once the PCLS return line breaks vacuum, the PCLS pumps cannot draw more water out of the SCAS. This arrangement ensures that the PCLS pumps cannot draw the water out of the SCAS cooling channels.

The use of centrifugal pumps and an air separator prevents the PCLS from effectively voiding the cooling channels by pumping air into the SCAS.

Malfunctions or leaks in the PCLS do not cause uncontrolled release of primary cooling water outside the radiologically controlled area (RCA). The facility structure (FSTR) provides barriers at exits from the RCA to prevent the release of potentially contaminated water to the uncontrolled environment.

The PCLS piping penetrating confinement boundaries are provided with redundant isolation capabilities as shown in Figure 5a2.2-1. The automatic isolation valves are closed as part of an IU Cell Safety Actuation if the TSV reactivity protection system (TRPS) detects a malfunction of PCLS, inleakage of primary cooling water into the PSB, or outleakage of target solution into the primary cooling water. PCLS automatic isolation valves take a closed position upon loss of actuating power as described in Subsection 7.4.3.8

5a2.2.3 INSTRUMENTATION AND CONTROL

Pressure, flow, temperature, conductivity, and level instrumentation monitor the operating parameters of the PCLS.

Temperature instrumentation is provided to ensure the cooling water supply temperature remains within allowable limits despite variations in TSV power. Output from the temperature instrumentation is used for controlling the flow of RPCS water through the PCLS heat exchanger to regulate the cooling water supply temperature at the SCAS cooling water inlet.

Flow instrumentation is provided to monitor the flowrate of the PCLS cooling water. The PCLS is normally operated as a constant flowrate system during irradiation. However, the PCLS may operate with either one or both pumps operating.

If the PCLS temperature or flowrate is outside allowable limits, the TRPS initiates an IU Cell Safety Actuation, resulting in a transfer of the target solution to the TSV dump tank where it is cooled by natural convection to the light water pool.

Expansion tank level instrumentation provides indication of loss of cooling water, such as by evaporation or radiolysis. Addition of makeup cooling water is a manual operation. Expansion tank level instrumentation can also perform a leak detection function as described in Subsection 5a2.2.6.

Conductivity instrumentation is provided to measure the conductivity of the PCLS water and monitor the performance of the PCLS cleanup side stream. Conductivity instrumentation can also perform a leak detection function as described in Subsection 5a2.2.6.

The PCLS pressure, flow, temperature, and expansion tank level indications are available locally and in the control room. Sampling and analysis of cooling water from the PCLS is performed locally. System operational controls are in the control room.

5a2.2.4 RADIATION MONITORS AND SAMPLING

The RVZ1e line ventilating the PCLS expansion tank headspace is equipped with radiation monitors as described in Subsection 9a2.1.1.

Sampling and analysis of the water from the PCLS is performed to ensure that the water quality requirements are being maintained and contaminants are not present in the cooling water. Maintaining water quality ensures functional and safe operation by reducing corrosion damage and scaling. See Table 5a2.2-1 for water quality requirements. Sampling of cooling water for radiological contaminants is performed to detect possible leakage of target solution into the PSB.

5a2.2.5 PCLS INTERFACES

The system interfaces of the PCLS are listed in Table 5a2.2-3.

The PCLS cooling water is pumped through the PCLS heat exchanger, where the heat is transferred to the RPCS and subsequently transferred to the process chilled water system (PCHS), where it is dissipated to the environment.

The PCLS cooling water leaves the SCAS and enters the PCLS air separator, which allows entrained radiolytic gas to separate from the cooling water. Besides hydrogen and oxygen, the headspace contains air, water vapor, and small amounts of N-16 and argon-41 (Ar-41). An interface between the RVZ1e and the expansion tank allows radiolytic gases to be purged to RVZ1e, preventing the buildup of hydrogen gas. Ambient air from within the primary confinement boundary is drawn through a flame arrestor and filter for sweeping of the expansion tank headspace.

Makeup water is added manually from the facility demineralized water system (FDWS), as described in Section 5a2.6. The PCLS piping includes backflow prevention components at the interface with the FDWS. This prevents possibly contaminated PCLS cooling water from coming in contact with the makeup water. The backflow prevention components help ensure the ALARA guidelines in Chapter 11 are met.

5a2.2.6 LEAK DETECTION

Leak detection is provided by the PCLS expansion tank level instrumentation, TSV dump tank level instrumentation, and conductivity instrumentation. Leak detection is also provided by radiation monitoring and sampling, as discussed in Subsection 5a2.2.4.

The expansion tank includes level instruments that allows operators to trend levels within the PCLS, which can indicate slow leaks of cooling water. Additionally, level indication in the TSV dump tank provides indication of inleakage of cooling water into the PSB. If inleakage into the PSB is detected, the TRPS initiates an IU Cell Safety Actuation.

Conductivity instrumentation can detect increases in conductivity of the PCLS cooling water resulting from inleakage of target solution.

5a2.2.7 HYDROGEN LIMITS

Radiolysis of the primary cooling water and the light water pool water results in the generation of hydrogen and oxygen gases. These gases must be vented to prevent the buildup of hydrogen. The RVZ1e draws air from the primary confinement and through the PCLS expansion tank headspace to dilute hydrogen within the primary confinement and expansion tank while the PCLS system is required to be in operation.

During full-power irradiation, up to approximately 0.15 standard cubic feet per hour (scfh) (70 standard cubic centimeters per minute [sccm]) of hydrogen gas is calculated to be generated in the primary cooling water and up to approximately 0.38 scfh (180 sccm) of hydrogen is calculated to be generated in the light water pool.

RVZ1e provides a nominal flowrate of approximately 1 standard cubic feet per minute (scfm) (28 standard liter per minute [slpm]) to the expansion tank headspace while the PCLS system is required to be in operation. The relatively low nominal flowrate maintains hydrogen concentrations within the primary confinement and expansion tank below 1 percent by volume while minimizing release of Ar-41 to the facility stack. Rates of Ar-41 production and release are described in Section 11.1.

5a2.2.8 TECHNICAL SPECIFICATIONS

Certain material in this section provides information that is used in the technical specifications. This includes limiting conditions for operation, setpoints, design features, and means for accomplishing surveillances. In addition, significant material is also applicable to, and may be used for the bases that are described in the technical specifications.

Table 5a2.2-1 – PCLS Operating Parameters

PCLS Parameter	Nominal Values
Cooling Medium	Water
Cooling Medium Makeup Source	Facility demineralized water system (FDWS)
Heat Exchanger Duty	580,000 Btu/hr (170 kW) per irradiation unit (IU) cell
Cooling Medium Supply Temperature	59°F to 77°F (15°C to 25°C)
Cooling Medium Flow Rate	Minimum flow rate: [ ]$^{\text{PROP/ECI}}$ Nominal flow rate: [ ]$^{\text{PROP/ECI}}$
Cooling Medium Quality	Conductivity: < 5 micromho per centimeter (μmho/cm) pH: 5.5 to 7.5
System Type	Forced cooling water, closed loop
System Design Pressure	100 pounds per square inch (psi)
System Design Temperature	200°F (93°C)
Material of Construction and Fabrication	Major components are fabricated from austenitic stainless steel

Table 5a2.2-2 – PCLS Components

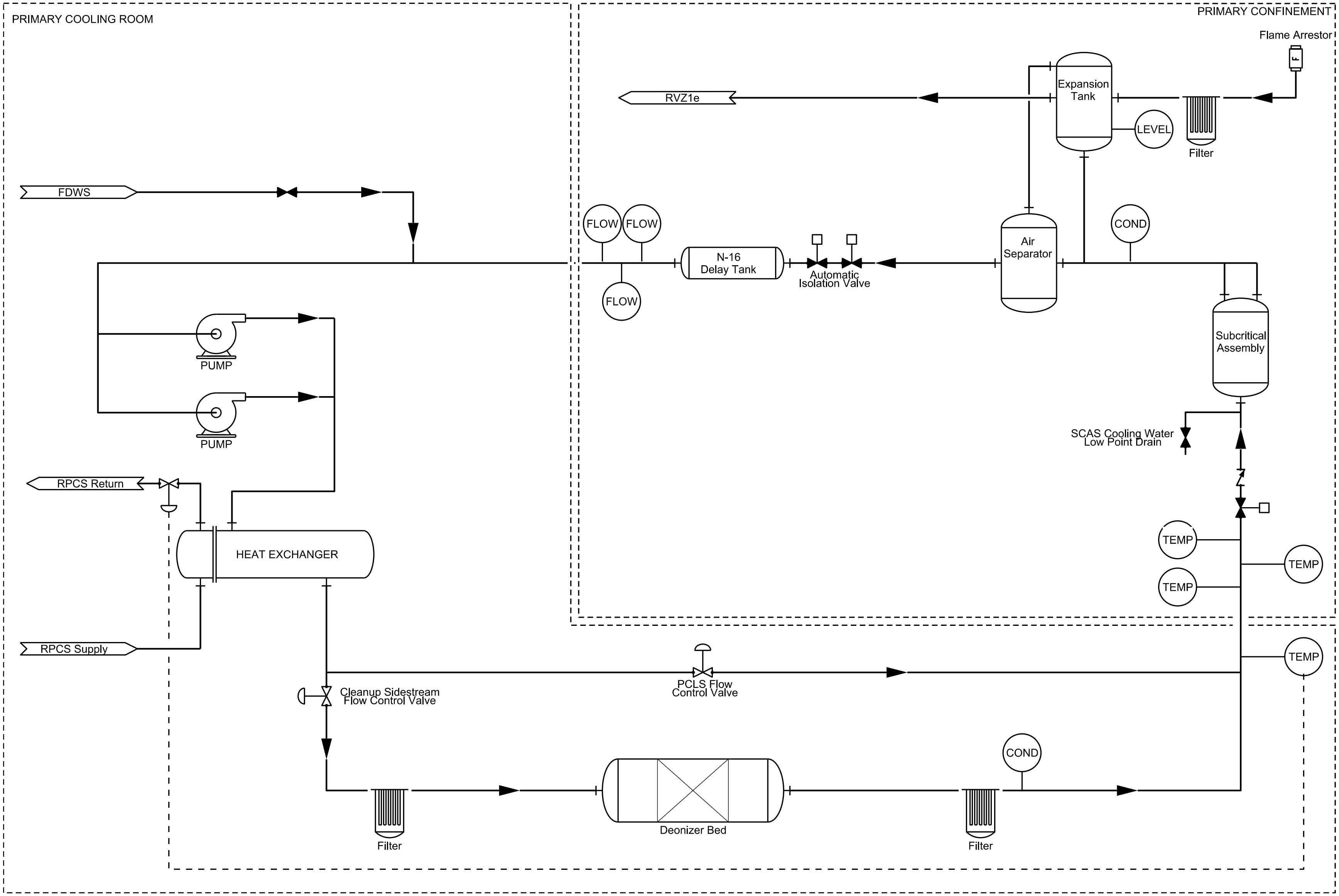
Component	Functions	Code/Standard
PCLS heat exchanger	Transfers heat from PCLS cooling loop to the RPCS	ASME BPVC, Section VIII, Division 1 (ASME, 2010)
PCLS expansion tank	Provides thermal expansion protection and pump head, and facilitates cooling loop level monitoring	ASME BPVC Section VIII, Division 1 (ASME, 2010)
Piping components	PCLS cooling loop piping	ASME B31.3 (ASME, 2013)
Nitrogen-16 (N-16) delay tank	Allows for the decay of N-16 that is generated in the cooling water by neutron activation of oxygen	ASME B31.3 (ASME, 2013)
PCLS pumps	Circulates PCLS cooling water through system components	Note(a)
PCLS instrumentation	Provides indication of PCLS operating parameters	See Chapter 7 for safety-related instrumentation See Note(a) for nonsafety-related instrumentation
PCLS air separator	Allows entrained radiolytic gas to leave the cooling water and enter into the expansion tank where it is vented to prevent the buildup of hydrogen in the system	ASME BPVC Section VIII, Division 1 (ASME, 2010)
PCLS flame arrestor with filter	Prevents the ignition of hydrogen in the PCLS expansion tank if RVZ1e flow through the expansion tank is lost	Note(a)
PCLS deionizer bed	Removes dissolved ions from the PCLS cooling water	Note(a)

a) Commercially available equipment designed to standards satisfying system operation.

Table 5a2.2-3 – PCLS System Interfaces

System	Interface Description
Radioisotope process cooling water system (RPCS)	The RPCS interfaces with each of the eight instances of PCLS inside the radiologically controlled area (RCA). Nonsafety-related manual isolation valves are located at the interface with PCLS.
Facility demineralized water system (FDWS)	The FDWS interfaces with each of the eight PCLS cooling loops inside the RCA. The FDWS interfaces with the PCLS downstream of a FDWS vacuum breaker. Nonsafety-related manual isolation valves are located at the interface with PCLS.
Subcritical assembly system (SCAS)	The SCAS interfaces with the PCLS in each of the eight light water pools located in the irradiation facility (IF).
Normal electrical power supply system (NPSS)	The NPSS provides power to PCLS process skid, including pumps and instrumentation, located inside the IF.
Uninterruptible electrical power supply system (UPSS)	The UPSS provides the PCLS safety-related instrumentation with electrical power during normal conditions and during and following design basis events.
TSV reactivity protection system (TRPS)	The PCLS provides instrumentation for the TRPS to monitor variables important to the safe operation of the PCLS. The TRPS provides controls to the PCLS components to perform safety actuations when monitored variables exceed predetermined limits.
Process integrated control system (PICS)	The PICS monitors and controls the PCLS process parameters, utilizing the instrumentation and controlled components within the IF.
Radiological ventilation zone 1 (RVZ1)	The RVZ1 provides an exhaust path from the headspace of each of the eight PCLS expansion tanks. The PCLS removes radiolytic gas from the cooling water and vents it to prevent combustible gas mixtures from forming.
Radiological ventilation zone 2 (RVZ2)	The RVZ2 provides an indirect source of makeup air into the PCLS expansion tanks via the supply air provided to the IF through the primary confinement.

Figure 5a2.2-1 – Primary Closed Loop Cooling System Flow Diagram



5a2.3 RADIOISOTOPE PROCESS FACILITY COOLING SYSTEM

5a2.3.1 DESIGN BASES AND FUNCTIONAL REQUIREMENTS

The radioisotope process facility cooling system (RPCS) removes heat generated from within the radiological control area (RCA) and rejects the heat to the process chilled water system (PCHS). The RPCS is an intermediate closed-loop forced liquid cooling system that recirculates cooling water. The RPCS removes heat from the primary closed loop cooling system (PCLS), the neutron driver assembly system (NDAS) cooling cabinets, the target solution vessel off-gas system (TOGS), the recirculating heating, ventilation, and air conditioning (HVAC) fan-coil units that are part of the radiological ventilation zone 1 recirculating cooling system (RVZ1r), the recirculating HVAC fan-coil units that are part of the radiological ventilation zone 2 recirculating cooling system (RVZ2r), the target solution preparation system (TSPS), the process vessel vent system (PVVS), and the molybdenum extraction and purification system (MEPS). The total demand placed on the RPCS by other systems is approximately 11.6 million British thermal units per hour (MMBtu/hr) (3400 kilowatts [kW]). The RPCS consists of a heat exchanger, pumps, system expansion tank, valves, instrumentation, and heat exchanger interfaces identified above. The RPCS major equipment is located in the RPCS room, within the RCA.

The process functions of the RPCS are to:

- maintain higher pressure than the cooling systems served at the respective interfaces;
- remove process heat from systems served;
- maintain cooling water quality to reduce corrosion and scaling; and
- reject heat to the PCHS.

The RPCS is a nonsafety-related system and is not credited with preventing or mitigating any design basis events. See Figure 5a2.3-1 for the process flow diagram of the RPCS. See Table 5a2.3-1 for the RPCS design and operating parameters. See Table 5a2.3-2 for the RPCS components.

5a2.3.2 RPCS ANALYSES

The cooling function of the RPCS is not credited in the safety analysis for any system served by the RPCS. If active cooling to the TSV and neutron multiplier is unavailable due to a loss of the RPCS, irradiation of the target solution will be suspended. Any target solution in the TSV will be transferred from the TSV to the TSV dump tank which is passively cooled by the light water pool. Section 4a2.4 provides a discussion of the heat removal capacity of the light water pool. Loss of cooling design basis accidents are discussed in Subsection 13a2.1.3.

A pressure cascade is maintained at each system heat exchanger that receives service such that the RPCS cooling water is maintained at a higher pressure than those systems with the potential to contaminate the RPCS. Additionally, the PCHS is maintained at a higher pressure than the RPCS at the RPCS heat exchanger so that any leakage between the RPCS and the PCHS will tend to leak into the RPCS.

Makeup water to the RPCS is from the facility demineralized water system (FDWS) as described in Section 5a2.6. The RPCS piping includes backflow prevention components at the interface with the FDWS. This prevents potentially contaminated RPCS cooling water from contacting the makeup water. The air-gap backflow prevention components help ensure the as low as reasonably achievable (ALARA) guidelines in Chapter 11 are met.

5a2.3.3 INSTRUMENTATION AND CONTROL

The process integrated control system (PICS) monitors the RPCS pressure, flow, temperature, and conductivity to ensure operation within design parameters. Instrumentation is located in the RPCS loop to obtain accurate system operating information. Setpoints ensure that operators are alerted when operating conditions are out of specification. Pressure, flow, and temperature are monitored within the RPCS to ensure that the system is operating within design conditions. Flow control is provided on the downstream side of each interfacing systems heat exchanger.

A conductivity analyzer is located near the RPCS heat exchanger and pump to monitor the conductivity of the RPCS cooling water. If the conductivity measurement is out of system operable parameters, operators are alerted such that the appropriate corrective actions can be taken. This protection limits corrosion and scaling damage in the RPCS system. Pressure, flow, and temperature instrumentation on the supply and return lines of the RPCS can indicate a malfunction in the system with an increase in pressure drop and/or low system flow. See Table 5a2.3-1 for the RPCS operating parameters.

The heat removal provided by RPCS to the PCLS is controlled by adjusting the RPCS flow rate to each heat exchanger. The RPCS flow rate is controlled on the return side of the process system heat exchanger by means of a modulating flow control valve. This arrangement ensures that the pressure differential between the RPCS and the PCLS is maintained, regardless of the position of the temperature control valves.

5a2.3.4 RADIATION MONITORS AND SAMPLING

The design of the cooling system ensures that release of radioactivity through the secondary cooling system to the unrestricted environment will not lead to potential exposures to the public in excess of the requirements of 10 CFR 20 and the ALARA program guidelines. The RPCS is maintained at a higher pressure than the systems served. Furthermore, the RPCS is a closed loop system located inside the RCA. The facility structure (FSTR) provides barriers at exits from the RCA to prevent the release of potentially contaminated cooling water to the uncontrolled environment.

Sampling and analysis of cooling water from the RPCS is performed to ensure radiological contaminants are below acceptable limits. If unacceptable levels of contamination are found, the system will be shut down and the contaminated cooling water will be purified using ion exchange beds. Operators then inspect the malfunctioning equipment and remedy the issue accordingly.

Sampling and analysis of the cooling water from the RPCS is also performed to ensure that the water quality requirements are being maintained. Maintaining cooling water quality minimizes the potential for damage due to corrosion and scaling. Table 5a2.3-1 describes the RPCS cooling water quality requirements.

5a2.3.5 OTHER INTERFACES

The RPCS components are listed in Table 5a2.3-2, including design codes and standards. The RPCS interfaces with the PCHS at the RPCS heat exchanger located within the RCA boundary. The system interfaces of the RPCS are listed in Table 5a2.3-3.

5a2.3.6 TECHNICAL SPECIFICATIONS

There are no technical specification parameters identified for the RPCS.

Table 5a2.3-1 – RPCS Operating Parameters

Parameter	Nominal Value
Cooling Medium	Water
Cooling Medium Makeup Source	FDWS
Supply Conditions	Temperature: 40°F to 44°F (4.5°C to 6.5°C)
Return Conditions	Temperature: 60°F to 64°F (15.5°C to 17.5°C)
Design Pressure	100 pounds per square inch (psi)
Design Temperature	200°F (93°C)
Heat Exchanger Duty	11.6 MMBtu/hr (3400 kW)
Cooling Medium Flow Rate	Volumetric flow rate: < 3000 gallons per minute (gpm)
Cooling Medium Quality	Conductivity: < 2000 μmho/cm pH: 6 to 8. Based on recommendations for secondary cooling water parameters in IAEA No. NP-T-5.2 (IAEA, 2011).
System Type	RPCS is a forced liquid, closed loop cooling system circulating water to remove heat from PCLS and other process and non-process systems via heat exchangers.
Material of Construction and Fabrication	RPCS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.3-2.

Table 5a2.3-2 – RPCS Components

Component	Description	Code/Standard
RPCS heat exchanger	Transfers heat from RPCS to PCHS.	Note(a)
RPCS expansion tank	Provides thermal expansion protection for the RPCS piping and components.	Note(a)
RPCS buffer tank	Provided to increase the system volume to levels required to maintain system loop times.	Note(a)
Piping components	RPCS piping.	ASME B31.9 (ASME, 2017)
RPCS pump	Circulates RPCS water through system components.	Note(a)
RPCS instrumentation	Provide indication of RPCS operating parameters (pressure, temperature, flow, and level).	Note(a)

a) Commercially available equipment designed to standards to satisfy system operation.

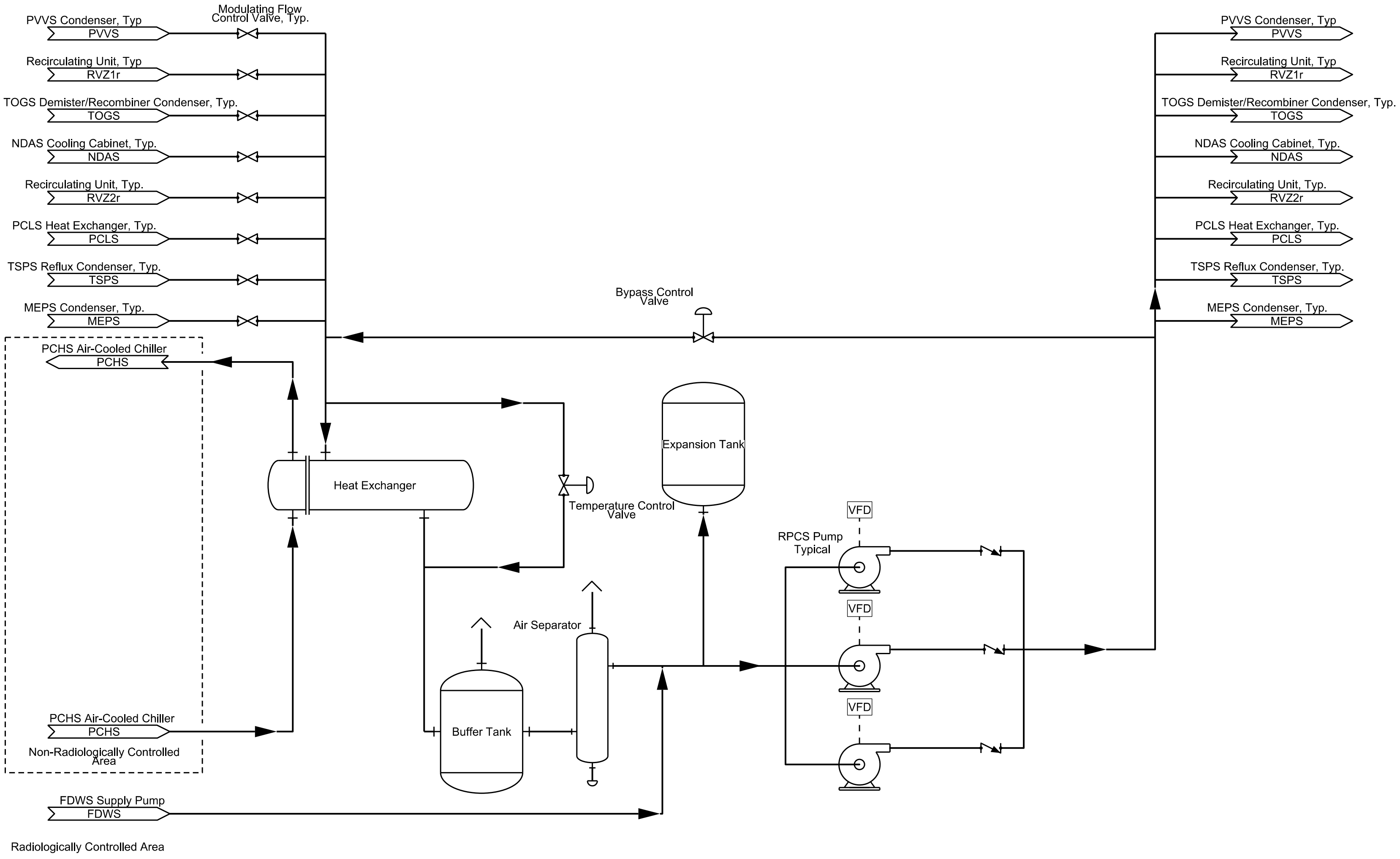
Table 5a2.3-3 – RPCS Interfaces
(Sheet 1 of 2)

System	Interface Description
Primary closed loop cooling system (PCLS)	The RPCS interfaces with each of the eight PCLS cooling loops inside the RCA. Nonsafety-related manual isolation valves are located at the interface with PCLS.
TSV off-gas system (TOGS)	Interfaces at the TOGS cooling water supply and return connections inside the RCA to condense water vapor and remove heat from recombiner condensers and condenser-demisters. Nonsafety-related manual isolation valves are located at the interface with TOGS.
Molybdenum extraction and purification system (MEPS)	Interfaces at the evaporator supply and return connections inside the RCA to facilitate condensation of water vapor. Nonsafety-related manual isolation valves are located at the interface with MEPS.
Process vessel vent system (PVVS)	Interfaces at the supply and return connections of the PVVS cooler and condensers within the RPF section of the RCA to reduce the PVVS process temperature and relative humidity. Nonsafety-related manual isolation valves are located at the interface with PVVS.
Process chilled water system (PCHS)	Interfaces at the supply and return connections of the RPCS heat exchanger inside the RCA and transfers heat from the RPCS to the PCHS so it can be released to the environment exterior to the RCA boundary. Nonsafety-related manual isolation valves are located at the interface with PCHS.
Target solution preparation system (TSPS)	Interfaces at the supply and return connections of the TSPS reflux condensers inside the RCA to mitigate liquid loss during dissolution. Supply and return isolation valves are located at the interface with TSPS.
Radiological ventilation Zone 1 recirculating cooling subsystem (RVZ1r)	Interfaces at the supply and return connections of the IU supplemental cooling system fan coil, exterior to the primary confinement boundary, inside the RCA. Nonsafety-related manual isolation valves are located at the interface with RVZ1r.
Radiological ventilation Zone 2 recirculating cooling subsystem (RVZ2r)	Interfaces at the supply and return connections of the recirculating unit fan coils inside the RCA. Nonsafety-related manual isolation valves are located at the interface with RVZ2r.
Facility demineralized water system (FDWS)	Interfaces upstream of the RPCS pumps inside the RCA to supply makeup water to the RPCS.
Neutron driver assembly system (NDAS)	Interfaces with each of the nine NDAS cooling cabinets within the RCA to remove heat from the independent NDAS cooling loops.

Table 5a2.3-3 – RPCS Interfaces
(Sheet 2 of 2)

System	Interface Description
Process integrated control system (PICS)	PICS monitors and controls RPCS actuators and instrumentation on valves, piping, and components.
Normal electrical power supply system (NPSS)	The NPSS provides power to RPCS equipment and instrumentation.

Figure 5a2.3-1 – Radioisotope Process Facility Cooling System Flow Diagram



5a2.4 PROCESS CHILLED WATER SYSTEM

5a2.4.1 DESIGN BASIS AND FUNCTIONAL REQUIREMENTS

The process chilled water system (PCHS) removes heat from the radioisotope process facility cooling system (RPCS) from within the radiologically controlled area (RCA) and rejects the heat to the environment. The PCHS interfaces with the RPCS heat exchanger and is comprised of circulation pumps, flow control valves, an expansion tank, a buffer tank, a glycol makeup unit, instrumentation, and packaged air-cooled chillers. The PCHS is a forced liquid, convective flow, closed loop cooling system that uses air-cooled chillers to facilitate heat rejection to the environment. The PCHS is designed to remove the total heat transfer demand placed on RPCS by other systems.

The PCHS is a nonsafety-related system and is not credited with preventing or mitigating any design basis events. Table 5a2.4-1 provides the PCHS operating parameters. Table 5a2.4-2 provides a description of PCHS components. Figure 5a2.4-1 provides a process flow diagram of the PCHS.

The process functions of the PCHS are to:

- remove heat from the RPCS heat exchangers;
- reject heat to the environment;
- maintain water quality to reduce corrosion and scaling; and
- prevent freezing of exterior piping and components.

The PCHS is designed for local outdoor operation. The system is operated with a propylene glycol/water mixture through the RPCS heat exchanger. Process generated heat is transferred from the facility process systems into the RPCS inside the RCA. The RPCS transfers this process heat to the PCHS through the RPCS heat exchanger, located inside the RCA. The PCHS then routes the process heat outside the RCA, and ultimately out of the facility to air-cooled chillers. The PCHS is provided makeup water from the facility demineralized water system (FDWS), which is described in Section 5a2.6, and glycol through a manual fill point for normal operation. Table 5a2.4-1 describes the PCHS water quality requirements.

5a2.4.2 PROCESS CHILLED WATER SYSTEM ANALYSES

The PCHS is designed to remove the total heat transfer demand placed on the RPCS by other systems of approximately 11.6 MMBtu/hr (3400 kW). The PCHS is maintained at a higher pressure than the RPCS to ensure that leakage at the system interface heat exchanger flows from potentially less contaminated cooling water to potentially more contaminated cooling water.

5a2.4.3 INSTRUMENTATION AND CONTROL

The PCHS provides output signals to the process integrated control system (PICS) for the monitoring of cooling water temperatures, pressures, tank level, and flow rates.

Pressure, flow, tank level, and temperature measurement instrumentation are strategically located in the PCHS cooling loop to obtain system operating information. Setpoints ensure that operators are alerted when an operating condition is out of specification. Buffer tank level setpoints are monitored to indicate high or low system volume conditions.

5a2.4.4 RADIATION MONITORS AND SAMPLING

The RPCS, transfers heat from the PCLS to the PCHS. The PCHS dissipates the heat from the RPCS to the environment. The RPCS is maintained at a lower pressure than PCHS at the RPCS heat exchanger as such any leakage between RPCS and PCHS would tend to leak into RPCS. The PCLS, RPCS, and PCHS are closed loop systems. Samples of cooling water are analyzed for contamination and conductivity. The contaminated volume of cooling water is recycled in either an on-site recycling unit or a mobile service unit. Water quality is maintained to reduce corrosion and scaling in the system. System cooling water level is monitored to provide indication of system in-leakage or out-leakage. These design features ensure that radioactivity is not released through the PCHS to the unrestricted environment and will not lead to potential exposures of the public in excess of the requirements of 10 CFR 20 and the as low as reasonably achievable (ALARA) program guidelines.

The system interfaces of the PCHS are listed in Table 5a2.4-3.

5a2.4.5 TECHNICAL SPECIFICATIONS

There are no technical specification parameters identified for the PCHS.

Table 5a2.4-1 – PCHS Operating Parameters

PCHS Parameter	Nominal Values
Cooling medium	Propylene glycol/water
Cooling medium make-up source	FDWS with manual addition of propylene glycol
Supply conditions	Temperature: 30°F to 40°F (-1°C to 4.5°C)
Return conditions	Temperature: 50°F to 60°F (10°C to 15.5°C)
Design pressure	160 psi
Design temperature	200°F (93.3°C)
Environment	Design dry bulb temperature (DBT) range: -10°F to 91.5°F (-23°C to 33°C)
Chiller heat duty	11.6 MMBtu/hr (3400 kW)
Cooling medium flow rate	Volumetric flow rate: < 2200 gallons per minute (gpm)
System type	PCHS is a forced liquid, closed loop cooling system circulating propylene glycol/water. The PCHS removes heat from the RPCS heat exchangers and transfer it to air-cooled chillers located outside of the facility.
Material of construction and fabrication	PCHS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.4-2.
Heat dissipation	This system dissipates heat to the environment through air-cooled chillers.

Table 5a2.4-2 – PCHS Components

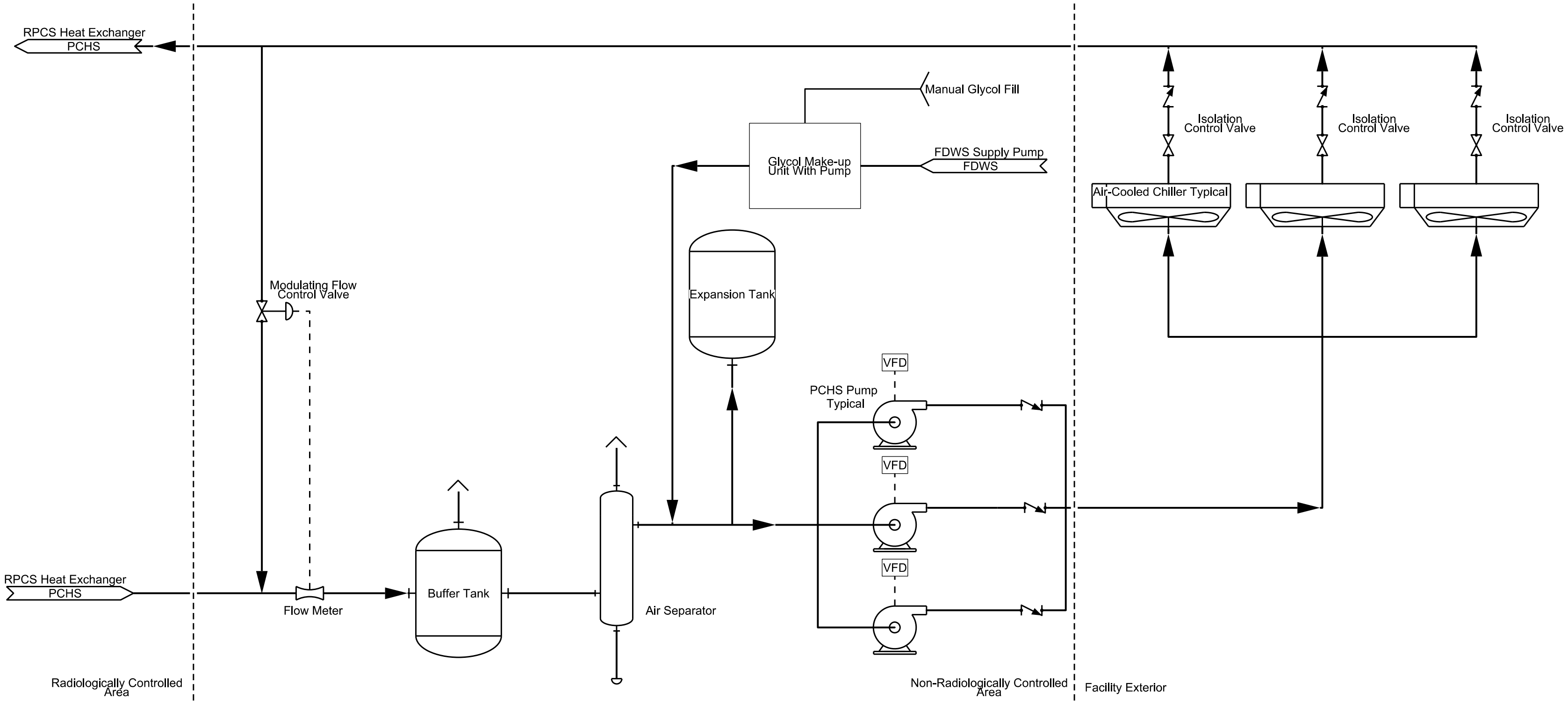
Component	Description	Code/Standard
PCHS chiller	Transfers heat from PCHS to the environment.	Note (a)
PCHS expansion tank	Provides thermal expansion protection for the PCHS piping and components.	Note (a)
PCHS buffer tank	Provided to increase the system volume to levels required to maintain system loop times.	Note (a)
PCHS pump	Circulates PCHS Coolant through system components	Note (a)
Piping components	PCHS piping.	ASME B31.9 (ASME, 2017)
Instrumentation	Provide indication of PCHS operating parameters (pressure, temperature, flow, and level).	Note (a)

a) Commercially available equipment designed to standards to satisfy system operation.

Table 5a2.4-3 – PCHS System Interfaces

System	Interface Description
Radioisotope process cooling system (RPCS)	Interfaces at the RPCS heat exchangers inside RCA. The PCHS removes heat from the RCA through the RPCS heat exchangers and rejects the heat to the environment outside the RCA.
Atmospheric environment	Interfaces at the PCHS chillers. Transfers heat from the PCHS through air chillers to the environment outside of the RCA boundary.

Figure 5a2.4-1 – Process Chilled Water System Flow Diagram



5a2.5 PRIMARY CLOSED LOOP COOLING SYSTEM CLEANUP SIDE STREAM

5a2.5.1 DESIGN BASES AND PROCESS FUNCTIONS

The primary closed loop cooling system (PCLS) cleanup side stream maintains the required water quality limits of the PCLS.

The following are the process functions of the PCLS cleanup side stream:

- Maintain water quality to reduce corrosion and scaling; and
- Limit concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation to achieve as low as reasonably achievable (ALARA) goals.

The PCLS cooling water is treated to meet water quality limits discussed in Table 5a2.2-1. The cleanup components are located on a side stream through which the PCLS diverts a portion of the cooling water flow. The components that perform the PCLS cooling water treatment are located within the PCLS cleanup side stream flow path.

The PCLS cleanup side stream includes conductivity instrumentation to monitor water quality, a deionizer bed to remove ionic species, and filters on the inlet and outlet of the deionizer bed to remove particulates from the cooling water.

Maintaining the design water quality limits corrosion damage and scaling of the PCLS, the target solution vessel (TSV), and the neutron multiplier, which are components of the subcritical assembly system (SCAS). The PCLS cleanup side stream removes contaminates that could become activated and radioactive materials from the PCLS cooling water in order to meet ALARA occupational exposure goals described in Section 11.1. The PCLS cleanup side stream and its components are designed and selected so that malfunctions are unlikely. Malfunctions and leaks in the PCLS and the PCLS cleanup side streams are addressed in Subsection 5a2.2.2.

See Table 5a2.2-2 for the list of PCLS components and their functions.

The PCLS cleanup side stream components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.2-2.

5a2.5.2 PCLS CLEANUP SIDE STREAM CONTROL AND INSTRUMENTATION

The PCLS cleanup side stream instrumentation is located in the primary cooling room.

Conductivity instrumentation located at the outlet of the PCLS cleanup side stream measures the conductivity within the PCLS. The pH of the PCLS cooling water is monitored through sampling of the system and analysis of the cooling water is performed by the quality control and analytical testing laboratories (LABS). Pressure, flow, temperature, conductivity, and level instrumentation monitor the operating parameters of the PCLS as discussed in Subsection 5a2.2.3.

5a2.5.3 PCLS CLEANUP SIDE STREAM COMPONENTS AND LOCATIONS

The PCLS cleanup side stream components are located in the primary cooling room, directly adjacent to the IU cells.

Flow to the PCLS cleanup side stream is diverted after it exits the PCLS heat exchanger. Flow through the PCLS cleanup side stream is adjusted by means of a flow control valve in the PCLS cleanup side stream. After the PCLS cooling water is diverted to the PCLS cleanup side stream, it first flows through a pre-filter, through a deionizer bed and finally through a post-filter. Following this process, the PCLS cooling water side stream is reintroduced into the PCLS main flow path prior to entering the SCAS.

5a2.5.4 MAINTENANCE AND TESTING

The PCLS cleanup side stream pre-filters, post-filters, and deionizer units are replaced at regular intervals in accordance with maintenance procedures. Spent filters and deionizer units are disposed of as radioactive waste via the solid radioactive waste processing (SRWP) system. Further discussion of SRWP can be found in Section 9b.7. Subsection 11.2.2 addresses compliance with 10 CFR 20 and presents ALARA guidelines relative to radioactive waste control. Table 11.2-1 provides a list of solid radioactive wastes including an estimate of annual quantities generated and disposal destinations.

Sampling and testing of the PCLS cooling water is performed as described in Subsection 5a2.2.5.

Isolating the PCLS cleanup side stream from the associated PCLS cooling loop for maintenance purposes does not disrupt irradiation unit (IU) operation or prevent safe IU shutdown.

5a2.5.5 PREDICTING, MONITORING AND SHIELDING RADIOACTIVITY

The PCLS cleanup side stream components are located entirely within the primary cooling room associated with their respective IU cell. Each primary cooling room is located within the irradiation cell biological shield (ICBS). The ICBS provides a barrier to protect SHINE facility personnel, members of the public, and various components and equipment of the SHINE facility by reducing radiation exposure. Refer to Section 4a2.5 for information pertaining to ICBS shielding requirements. Radiation monitoring of the ICBS general area is provided as discussed in Section 7.7.

PCLS does not discharge radioactive liquid effluent from the facility; therefore, there are no liquid effluent monitors. Monitoring of closed loop process cooling water systems to detect cooling water leakage between primary and secondary circuits due to failures in heat exchangers and other system boundaries is provided.

As discussed in Subsection 5a2.2.2, PCLS piping penetrating confinement boundaries are provided with isolation capabilities. Automatic isolation valves on the PCLS supply and return lines exiting the IU cell are closed as part of an IU Cell Safety Actuation if the TSV reactivity protection system (TRPS) detects an outleakage of target solution into the primary cooling water. Furthermore, the PCLS equipment is located inside the primary cooling room and IU cell, which are shielded by ICBS. These design features limit exposure of personnel to radioactivity.

The PCLS is a closed loop system and is operated at a higher pressure than the TSV to reduce the potential for leakage of the target solution into the PCLS in the event of a breach. In the event of pressurization of the primary system boundary, potential leakage from the TSV would be contained within the PCLS. Table 11.1-9 identifies the various locations, types, and expected doses from liquid radioactive sources. Section 5a2.7 provides a discussion pertaining to control of nitrogen-16.

5a2.5.6 TECHNICAL SPECIFICATIONS

There are no technical specification parameters identified for the PCLS cleanup loop.

5a2.6 FACILITY DEMINERALIZED WATER SYSTEM

The facility demineralized water system (FDWS) provides makeup water to the primary closed loop cooling system (PCLS), radioisotope process facility cooling system (RPCS), facility chilled water system (FCHS), molybdenum extraction and purification system (MEPS) hot water loop subsystem, light water pool, and process chilled water system (PCHS). The FDWS provides a water supply to the radiological ventilation zone 2 (RVZ2) system and the facility ventilation zone 4 (FVZ4) system for humidity control. The quality control and analytical testing laboratories (LABS) and the facility chemical reagent system (FCRS) are supplied demineralized water from the FDWS. Operational cooling water loss in the PCLS and light water pool occurs gradually from radiolysis and evaporation. Water loss in the PCLS, RPCS, FCHS, MEPS hot water subsystem, and PCHS may also occur from off-normal events such as leaks or for maintenance. Makeup from the FDWS to the systems served is supplied through piping that contains backflow prevention. Transfers of makeup water from the FDWS to the cooling and heating systems are performed manually. Refer to Figure 5a2.6-1 for a flow diagram of the FDWS.

The FDWS is supplied water from the facility potable water system (FPWS). The FDWS includes a reverse osmosis (RO) skid and a RO storage tank located outside of the radiologically controlled area (RCA). The RO skid is a packaged unit that contains pre-filters, piping, valves, pumps, and RO membranes to supply RO water. The RO skid is located downstream of the backflow prevention device that acts as the system boundary between the FPWS and the FDWS. The demineralized water processed through the RO membrane into the RO storage tank outside of the RCA is supplied to end users outside the RCA requiring RO treated water as well as to the RO storage tank located inside the RCA. A second backflow prevention device is provided at the boundary where the FDWS enters the RCA.

The FDWS includes two recirculation loops (i.e., one inside the RCA and one outside the RCA) with two 100% capacity pumps for each recirculation loop. The two pumps are supplied water from the respective RO storage tank that has been filtered by the RO membrane on the RO skid. The pumps circulate water from the respective RO storage tank to a ring header either inside or outside the RCA and back to the respective tank. Only one of the two pumps in each recirculation loop is required to be operational for system service. Recirculated water is supplied directly to end users requiring RO-processed water, and through deionizers to other end users requiring deionized water. Table 5a2.6-1 identifies the RO-processed and deionized water end users.

The FDWS components are listed in Table 5a2.6-2, including design codes and standards.

Flow from the RO skid is controlled by level instrumentation in the RO storage tanks. Tank level is provided with high- and low-level alarms. Pressure is monitored at the outlet of the circulation pump where high- and low-level alarms are provided. Sampling and trending of the system is performed to detect malfunctions in the deionizer units and the RO skid. Sampling and trending serve to identify when replacement or repair is necessary.

The FDWS is not safety-related. On loss of normal power, the pumps will not be operational, as the FDWS is not relied on to provide water on loss of normal power.

Table 5a2.6-1 – FDWS End Users

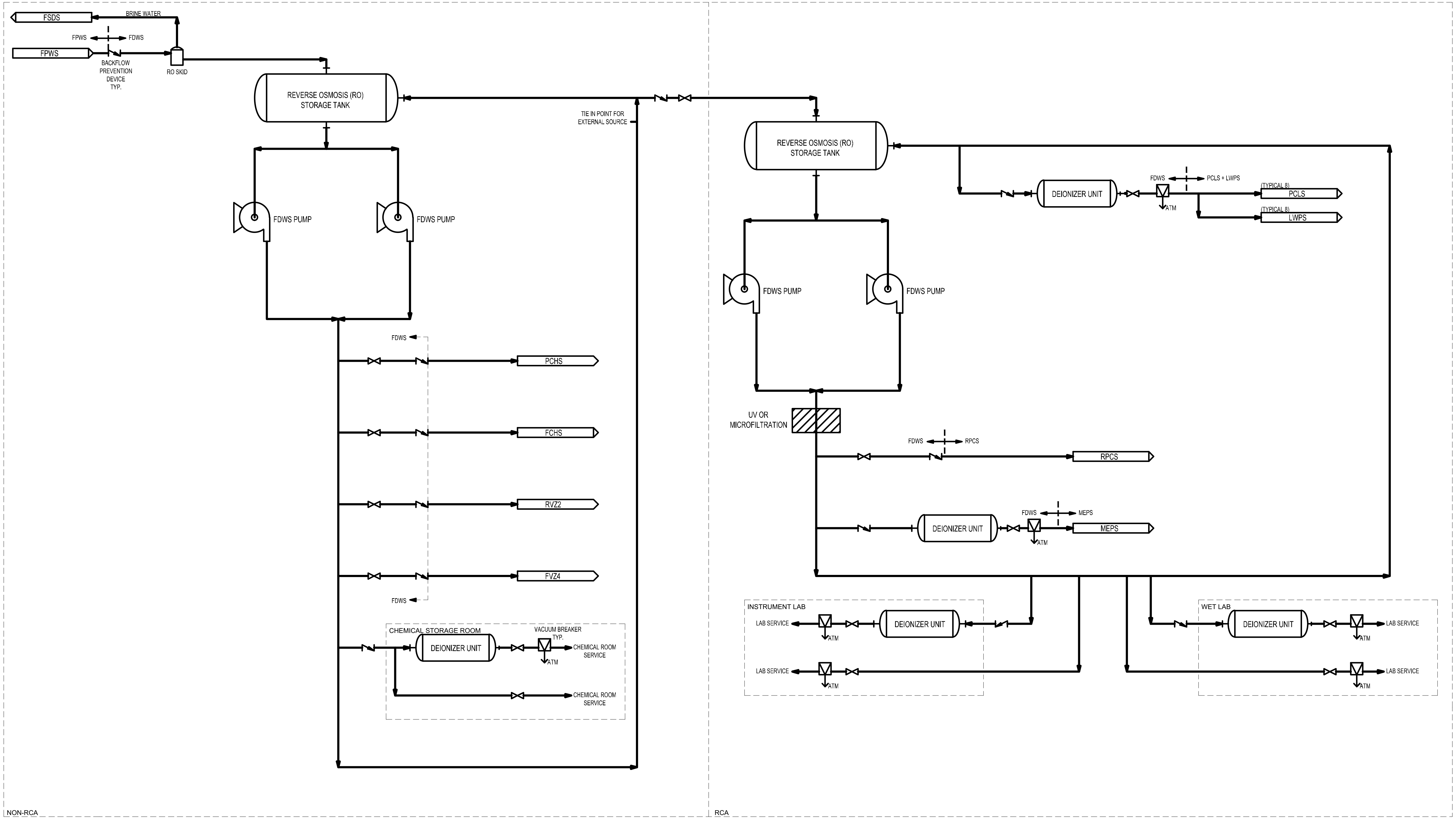
Reverse Osmosis Water End Users
Facility chilled water system (FCHS)
Facility chemical reagent system (FCRS) servicing the chemical storage room
Quality control and analytical testing laboratories (LABS) in the Wet and Instrument Laboratories
Process chilled water system (PCHS)
Radioisotope process facility cooling system (RPCS)
Radiological ventilation zone 2 (RVZ2)
Facility ventilation zone 4 (FVZ4)
Deionized Water End Users
The molybdenum extraction and purification system (MEPS) hot water loop subsystem
Facility chemical reagent system (FCRS) servicing the chemical storage room
Quality control and analytical testing laboratories (LABS) in the Wet and Instrument Laboratories
Primary closed loop cooling system (PCLS)
Light water pool system (LWPS)

Table 5a2.6-2 – FDWS Components

Component	Description	Code/Standard
Facility demineralized water system (FDWS) reverse osmosis (RO) skid	The RO skid is a packaged unit that contains pre-filters, piping, valves, pumps, and RO membranes.	Note(a)
FDWS deionizer units	Provided to house deionization resins for the removal of contaminants and the reduction of water conductivity.	Note(a)
FDWS RO storage tanks	Provided to maintain adequate RO system supply volumes.	Note(a)
FDWS pumps	Circulates FDWS RO water through system components.	Note(a)
Piping components	FDWS piping.	ASME B31.9 (ASME, 2011)
Instrumentation	Provide indication of FDWS operating parameters (pressure, temperature, conductivity, flow, and level).	Note(a)

a) Commercially available equipment designed to standards satisfying system operation.

Figure 5a2.6-1 – Facility Demineralized Water System Flow Diagram



5a2.7 NITROGEN-16 CONTROL

Nitrogen-16 (N-16) is generated in the PCLS and light water pool by the neutron activation of oxygen. The N-16 control is provided by the primary closed loop cooling system (PCLS) delay tank. As shown in Figure 5a2.2-1, a liquid delay tank is located downstream of the air separator, in the PCLS cooling loop flow path.

The N-16 delay tank provides additional holdup time to allow for sufficient decay of N-16 prior to exiting the shielding to meet with as low as reasonably achievable (ALARA) goals and the radiation protection program. In addition, to allowing a portion of the N-16 to decay, a reduction in shielding wall thickness is realized as well as a reduction in the PCLS equipment radiation tolerance requirements.

The PCLS uses an air separator to remove entrained gases from the cooling water flow path. The PCLS air separators are vented to the headspace of the corresponding IU cell expansion tank inside the primary confinement boundary. The headspace of the PCLS expansion tank accepts separated gases, including N-16, and directs those gases via vent lines through the primary confinement boundary and into the radiological ventilation zone 1 exhaust (RVZ1e). The gas volumes of the expansion tank headspace and vent lines are sufficient to allow adequate decay of N-16 prior to the gases leaving the IU cell shielding.

Subsection 11.1.1 provides a discussion of airborne and liquid radiation sources at the main production facility, including N-16.

5a2.8 AUXILIARY SYSTEMS USING PRIMARY COOLANT

The primary closed loop cooling system (PCLS) provides cooling to the target solution vessel (TSV) and the neutron multiplier. SHINE facility auxiliary systems do not utilize the PCLS for cooling duty.

5a2.9 REFERENCES

AHRI, 2015. Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle, AHRI Standard 550/590 (I-P), Air-Conditioning, Heating, and Refrigeration Institute, 2015.

ASME, 2010. Rules for Construction of Pressure Vessels, ASME Boiler and Pressure Vessel Code, VIII, Division 1, American Society of Mechanical Engineers, 2010.

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IAEA, 2011. Good Practices for Water Quality Management in Research Reactors and Spent Fuel Storage Facilities, IAEA Nuclear Energy Series No. NP-T-5.2, International Atomic Energy Agency, 2011.

5b RADIOISOTOPE PRODUCTION FACILITY COOLING SYSTEMS

SHINE cooling systems are integrated throughout the facility as described in Section 5a2. The radioisotope process facility cooling system is described in Section 5a2.3.