CHAPTER 5

COOLING SYSTEMS

Table of Contents

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
/yr	per year
°F	degrees Fahrenheit
μmho	micromho
10 CFR 20	Title 10 of the Code of Federal Regulations Part 20
ALARA	as low as reasonably achievable
Ar-41	argon-41
Btu	british thermal unit
Btu/hr	british thermal units per hour
CAAS	criticality accident alarm system
CHWS	process chilled water
CHWS/R	chilled water supply/return
cm	centimeter
cm/yr	centimeters per year
D	deep
DI	deionized
ESF	engineered safety feature
FCHS	facility chilled water supply and distribution system
FDWS	facility demineralized water system
FIAS	facility instrument air system
FICS	facility integrated control system
FPS	facility power system
ft.	feet
gal.	gallon
gpm	gallons per minute
HLL	high liquid level
hr.	hour
IAEA	International Atomic Energy Agency

Acronyms and Abbreviations (cont'd)

Acronym/Abbreviation	Definition
in.	inch
IU	irradiation unit
kg	kilogram
km	kilometer
kW	kilowatt
lb.	pound
lb/min	pounds per minute
LCO	limiting condition for operation
LFL	lower flammable limit
LLL	low liquid level
LWPS	light water pool system
m	meter
MEPS	molybdenum extraction and purification system
mi.	mile
MM	million
MUPS	light water pool and primary closed loop cooling make-up system
N-16	nitrogen-16
NDAS	neutron driver assembly system
PCLS	primary closed loop cooling system
PFD	process flow diagram
PSAR	preliminary safety analysis report
psig	pounds per square inch gauge
PVVS	process vessel vent system
RCA	radiologically controlled area
RDS	radioactive drain system

Acronyms and Abbreviations (cont'd)

Acronym/Abbreviation	Definition
RLWE	radioactive liquid waste evaporation and immobilization system
RLWS	radioactive liquid waste storage system
RPCS	radioisotope process facility cooling system
SASS	subcritical assembly support structure
SCAS	subcritical assembly system
SHINE	SHINE Medical Technologies, Inc.
TOGS	TSV off-gas system
TPS	tritium purification system
TRPS	TSV reactivity protection system
TSV	target solution vessel
UNCS	uranyl nitrate conversion system
UREX	uranium extraction system
yd.	yard

CHAPTER 5

COOLANT SYSTEMS

5a1 HETEROGENOUS REACTOR COOLING SYSTEMS

The SHINE Medical Technologies, Inc. (SHINE) facility is not a reactor; therefore, this section does not apply to the SHINE facility.

5a2 IRRADIATION UNIT COOLING SYSTEMS

The irradiation unit (IU) cooling systems include the primary cooling system and secondary cooling system. The primary cooling system is comprised of the primary closed loop cooling system (PCLS) and light water pool system (LWPS). The secondary cooling system is referred to as the radioisotope process facility cooling system (RPCS). The cooling systems' heat flow pathway is shown in Figure 5a2.1-1.

The PCLS and LWPS provide the heat removal to the IU equipment that is submerged within the light water pool. The RPCS removes heat from the LWPS/PCLS and transfers it to the facility chilled water supply and distribution system (FCHS).

There are eight IUs that each include a PCLS and LWPS. The RPCS is a closed loop system that provides cooling water to all of the process areas within the RCA. This section focuses on the RPCS in relation to the IU PCLS/LWPS function.

The thermal partitions between the LWPS/PCLS and RPCS cooling systems are the heat exchangers at the system interfaces. These heat exchangers are shown in Figures 5a2.2-1 and 5a2.2-2 (the legend for process flow diagrams is provided in Figure 1.3-6). The thermal partition between the RPCS and FCHS is at the RPCS heat exchanger, shown in Figure 5a2.3-1. The heat exchangers used are plate and frame types. There is a positive pressure differential at each thermal partition such that a breach in a heat exchanger would result in uncontaminated water at higher pressure flowing into the potentially-radioactive water at a lower pressure.

This section describes the design bases and functions of the PCLS, LWPS, and RPCS. For detailed information on the three systems, see Sections 5a2.2, 5a2.3, and 5b.1.

The primary coolant cleanup loops provide treatment of the PCLS and LWPS coolant to meet water quality limits.

The MUPS provides makeup water to the PCLS and LWPS cooling loops.

5a2.1 SUMMARY DESCRIPTION

5a2.1.1 PRIMARY COOLING SYSTEM

The primary cooling system (LWPS and PCLS) removes heat from the IU during operation and transfers the heat to the RPCS via a heat exchanger.

The PCLS cooling loop removes heat directly from the TSV [Proprietary Information] around the TSV walls during normal irradiation and shut down conditions. [Proprietary Information]. Coolant removes heat from the TSV by forced convection as it is pumped [Proprietary Information] around the walls of the TSV. The PCLS cooling loop includes a heat exchanger, pump, and water treatment equipment. The PCLS is a closed-loop system.

The LWPS cooling loop removes heat from the light water pool by circulating the light water pool water through the LWPS cooling loop during normal irradiation and shut down operations. During normal operations, the majority of the heat actively removed by the LWPS is from the neutron multiplier and neutron driver target chamber with a small amount from the pool due to gamma radiation and neutron slowing down energy. During abnormal operation or accident scenarios, the light water pool passively removes decay heat from the neutron multiplier and TSV dump tank. The LWPS includes the light water pool and cooling loop components. The light water pool is approximately [Proprietary Information] and includes a 316L stainless steel liner attached to the concrete structure. The subcritical assembly support structure (SASS) and the TSV dump tank are submerged in the light water pool. The pump (1-LWPS-01P) suction is from the base of the light water pool and discharges to the SASS after passing through the LWPS heat exchanger (see Figure 5a2.2-1). The cooling water flows up the center of the SASS to cool the neutron multiplier and target chamber. The LWPS cooling loop includes a heat exchanger, pump, and water treatment equipment.

Each PCLS is designed to remove a minimum of [Proprietary Information] of heat from each IU during full-power operation. The LWPS is designed to remove a minimum of [Proprietary Information] of heat from each IU during full-power operation. The light water pool itself is designed to passively remove decay waste heat (post-IU shut down) during design basis accidents that result in a loss of PCLS and LWPS active cooling. A small amount of heat is also removed by the TSV off-gas system (TOGS).

The coolant used in the LWPS and PCLS is light water that follows the quality limits and design parameters described in Section 5a2.2.

For radiation exposure protection, see Subsection 5a2.2.10.

5a2.1.2 SECONDARY COOLING SYSTEM

The RPCS removes heat from the process heat exchangers within the RCA, including the PCLS and LWPS heat exchangers. The RPCS is a closed-loop cooling system that circulates cooling water to all process system users within the RCA boundary and transfers the absorbed heat to the FCHS via a plate and frame heat exchanger within the RCA boundary. The FCHS subsequently dissipates the heat to the environment outside of the RCA.

The RPCS is capable of removing [Proprietary Information] from the eight IU LWPS and PCLS loops. This is accomplished by circulating the LWPS water and PCLS water through a heat exchanger on each loop to transfer the heat to the RPCS cooling loop. The total RPCS heat duty from all process systems is approximately [Proprietary Information]. Active heat removal from these systems is not required for emergency cooling.

5a2.1.3 PRIMARY COOLANT CLEANUP

The LWPS and PCLS water is continuously treated to meet water quality limits discussed in Section 5a2.2. The cleanup components are located on a bypass loop for each PCLS and LWPS cooling loop that sends 1 to 10 percent of the cooling loop flow through the cleanup loop to continuously remove particulates and ionic species from the coolant.

The primary coolant cleanup loops include a conductivity analyzer, ion exchange column to remove ionic species, and filters on the inlet and outlet of the ion exchange column to remove particulates from the coolant. See Section 5a2.4 for the design parameters of this system.

5a2.1.4 PRIMARY COOLING MAKEUP WATER SYSTEM

The primary cooling makeup water system is referred to as the light water pool and primary closed loop cooling makeup system (MUPS) in the SHINE facility. The MUPS provides makeup water to the PCLS and LWPS cooling loops.

MUPS water is supplied from the facility demineralized water system (FDWS) to provide pretreated water to the PCLS and LWPS. See Table 5a2.5-1 for MUPS system specifications.

5a2.1.5 NITROGEN-16 CONTROL

There is no independent nitrogen-16 (N-16) control system. The radiation dose from N-16 is mitigated by shielding around the PCLS/LWPS components and the administrative controls defined by the radiation protection program.

5a2.2 PRIMARY COOLING SYSTEM

5a2.2.1 DESIGN BASIS

The primary cooling system provides heat removal to the IUs during normal irradiation and shutdown conditions. The primary cooling system in the SHINE facility is comprised of the PCLS and the LWPS cooling system for each IU.

The PCLS removes heat directly from the TSV [Proprietary Information] around the TSV walls during normal irradiation and shutdown conditions. The SASS is a stainless steel vessel and support system surrounding the TSV. It provides the shell-side for the coolant flow past the TSV. The heat removed by the PCLS loop is transferred to the secondary cooling system, or RPCS, at a plate and frame heat exchanger on each PCLS loop.

The LWPS circulates the light water pool water to remove heat generated during normal irradiation and shutdown conditions. The LWPS provides direct cooling to the neutron multiplier and target chamber and cooling to the TSV dump tank. The heat removed from the light water pool is transferred to the RPCS at a plate and frame heat exchanger on each LWPS loop. The light water pool component of this system is safety-related and provides passive cooling to the IU in design basis accident scenarios.

See Figure 5a2.2-2 for the process flow diagram and Table 5a2.2-1 for the specifications of the PCLS. See Figure 5a2.2-1 for the process flow diagram and Table 5a2.2-2 for the specifications of the LWPS. The RPCS interfaces with the primary cooling system at the two depicted heat exchangers, and is shown as chilled water supply (CHWS) and chilled water return (CHWR) in the figures.

Both primary cooling system loops include circulation pumps, heat exchangers, water treatment equipment, and connections to makeup water and waste treatment. The PCLS contains an expansion tank (1-PCLS-01T) to provide thermal expansion protection, head for the pump, and system volume level monitoring. The light water pool itself provides an expansion volume for the LWPS cooling loop.

5a2.2.2 PCLS PROCESS FUNCTIONS

The process functions of the PCLS cooling system are:

- Remove a minimum of [Proprietary Information] of heat from each TSV (eight total) during full-power IU operation by circulating deionized water [Proprietary Information].
- Maintain physical integrity of system pressure boundary.
- Maintain water quality to reduce corrosion and scaling.
- Limit concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation within ALARA guidelines.

5a2.2.3 SYSTEM PROCESS AND SAFETY FUNCTIONS

The process functions of the LWPS are:

- Remove a minimum of [Proprietary Information] of heat from the light water pool, neutron multiplier, and target chamber for each IU cell during full-power operation by circulating the light water pool water through the cooling loop.
- Maintain the normal temperature range of the light water pool.
- Maintain system physical integrity.
- Maintain water quality to reduce corrosion and scaling.
- Limit concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation within ALARA guidelines.

The safety functions of the LWPS are listed below:

- Provide decay heat cooling heat sink during design basis accidents.

5a2.2.4 TECHNICAL SPECIFICATION OPERATING PARAMETERS

There are no technical specification parameters identified for the PCLS or the LWPS.

5a2.2.5 PRIMARY COOLING SYSTEM COMPONENTS AND INTERFACES

The primary cooling system LWPS and PCLS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.2-3.

The system interfaces of the primary cooling system are listed in Table 5a2.2-4. Water treatment components associated with the primary cooling system are discussed in Section 5a2.4.

5a2.2.6 PCLS COOLING FUNCTIONS AND OPERATION

The PCLS removes heat directly from the TSV [Proprietary Information] around the TSV walls during normal irradiation and shut down operations. [Proprietary Information] The flow path of the [Proprietary Information]. The coolant system operates via forced convection during normal operation.

Once the heat from the TSV is transferred to the PCLS cooling water, the water enters the PCLS cooling water tank (1-PCLS-01T) to allow for thermal expansion, provide head for the circulation pump, and provide cooling loop volume monitoring.

The PCLS cooling water is pumped through the heat exchanger where the heat is transferred to the RPCS and then subsequently transferred to the FCHS where it is dissipated to the environment.

After the PCLS water is cooled to the nominal outlet temperature in Table 5a2.2-1, it is returned to the SASSA portion of the flow is diverted downstream of the heat exchanger, sending a small portion of the cooling water flow to water treatment equipment to remove ionic species and particulates.

The water quality specifications can be found in Table 5a2.2-1. The water treatment equipment is discussed in Section 5a2.4.

The PCLS continues to operate after the neutron driver assembly system (NDAS) is shut down to remove heat from the TSV.

5a2.2.7 LWPS COOLING FUNCTIONS AND OPERATION

The light water pool is a rectangular concrete structure of approximately [Proprietary Information]. The pool includes a 316 L stainless steel liner and is equipped with leak detection features. The approximate liquid volume of the pool is [Proprietary Information] when adjusted for IU equipment displacement. See Section 4a2.4.2 for physical property information about the light water pool structure.

The LWPS removes heat from the light water pool by circulating the pool water through the cooling loop during normal irradiation and shut down conditions. During normal operations, the majority of the heat actively removed by the LWPS is from the neutron multiplier and target chamber with a small amount from the pool due to gamma radiation and neutron slow down energy. During abnormal operation or accident scenarios, the light water pool passively removes decay heat from the neutron multiplier and TSV. The pump (1-LWPS-01P) suction is from the light water pool and discharge is at the bottom of the SASS after passing through the LWPS heat exchanger. The LWPS cooling loop is also active after the NDAS has been shut down to maintain the normal operation temperature range shown in Table 5a2.2-2.

The light water pool water enters the cooling loop and is pumped through the heat exchanger to transfer heat absorbed to the RPCS cooling loop. The RPCS subsequently transfers the heat to the FCHS where it is dissipated to the environment.

After the light water pool water is cooled to the nominal temperature in Table 5a2.2-2, it is returned to the SASS and light water pool. A portion of the flow is diverted downstream of the heat exchanger, sending a small portion of the cooling water flow to water treatment equipment to remove ionic species and particulates. The water quality specifications can be found in Table 5a2.2-2. The water treatment equipment is discussed in Section 5a2.4.

The light water pool acts as a heat reservoir to remove heat from the subcritical assembly system (SCAS). The pool provides a large reservoir to remove heat during normal irradiation operation and in the case of a design basis accident. Even with a loss of LWPS circulation, the light water pool absorbs the decay heat after the NDAS has been shut down. See Chapter 13 for more discussion of accident scenarios.

Hydrogen gas accumulation in the light water pool head space is not possible since the pool surface is open to the IU cell atmosphere.

5a2.2.8 INSTRUMENTATION AND SAMPLING

Pressure, flow, and level monitoring instrumentation are located on the PCLS and LWPS to monitor the operating parameters of the loops. Flow, pressure, and temperature instrumentation are located around the major components of the cooling loops.

Sampling and analysis of the water from the PCLS and LWPS is performed periodically to ensure that the water quality requirements are being maintained and contaminants are not present in the cooling loops. Maintaining water quality ensures functional and safe operation by reducing corrosion damage and scaling. See Table 5a2.2-1 for water quality requirements. Water treatment instrumentation is further discussed in Section 5a2.4. Sampling for radiological contaminants is performed to detect possible leakage in the primary system boundary.

Conductivity analyzers are located near the PCLS and LWPS heat exchangers and pumps to detect the cation level in the LWPS and PCLS water.

5a2.2.9 SECONDARY COOLING SYSTEM INTERACTION

The primary cooling system loops transfer heat removed from the SCAS and light water pool to the RPCS through the plate and frame heat exchangers (1-LWPS-01A, 1-PCLS-01A). See Table 5a2.3-1 for the operating conditions of the RPCS.

Radiation monitoring and water purity sampling requirements will be described for the RPCS in the FSAR. This will include concentration limits and sampling frequency.

The pressure of the RPCS water is greater than the pressure of the primary cooling system cooling loops to ensure that contaminants will not leak into the RPCS water system if a plate or seal in a heat exchanger (1-LWPS-01A/1-PCLS-01A) leaks. In addition to pressure detection on PCLS and LWPS loops, pressure monitoring instrumentation (including low pressure alarms) is located on the piping of the RPCS to verify sufficient RPCS pressure is maintained.

5a2.2.10 RADIATION EXPOSURE PROTECTION

The primary cooling system piping confines the cooling water within the IU cell and within the primary cooling enclosures located adjacent to the IU cells. The cooling loops are constructed of materials that effectively resist corrosion to limit the radiation exposure of the workers and surrounding equipment.

The light water pool and TSV are contained within the IU cell, which also provides confinement to the components of the primary cooling system within the IU cell boundary.

The PCLS and LWPS will contain N-16 during normal IU operation. The PCLS and LWPS equipment located outside of the IU cell include adequate biological shielding to meet radiation exposure goals defined in Subsection 11.1.2.

Table 5a2.2-1 PCLS Specifications

PCLS Parameter	Nominal Value
Coolant Material	Light water
Coolant Source	FDWS
Inlet Conditions (at return from TSV)	Temperature: 80°F Pressure: 3 pounds per square inch gauge (psig)
Outlet Conditions (at supply to TSV)	Temperature: 68°F Pressure: 5 psig
Heat Exchanger Duty	[Proprietary Information]
Coolant Flow Rate	Mass flow rate: [Proprietary Information] Volumetric flow rate: [Proprietary Information]
Coolant Quality	Conductivity: <5 micromho per cm (μmho/cm) pH: 5.5 to 7.5 The IAEA (2011) provides case studies on primary cooling systems in various reactor facilities. These water quality limits reflect the case studies in that report.
System Type	A cooling water closed loop.
Material of Construction and Fabrication	The primary cooling system LWPS and PCLS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.2-3.

Table 5a.2.2-2 LWPS Specifications

LWPS Parameter	Nominal Value
Coolant Material	Water
Coolant Source	FDWS
Temperature Range	68°F to 75°F
Inlet Conditions (at return from light water pool volume)	Temperature: 75°F Pressure: 0 psig
Outlet Conditions (at supply to SASS)	Temperature: 68°F Pressure: 3 psig
Heat Exchanger Duty	[Proprietary Information]
Coolant Flow Rate	Mass flow rate: [Proprietary Information] Volumetric flow rate: [Proprietary Information]
Coolant Quality	Conductivity: <5 μmho/cm pH: 5.5 to 7.5 The IAEA (2011) provides case studies on primary cooling systems in various facilities. These water quality limits reflect the case studies in that report.
System Type	A cooling water closed loop that removes heat from the light water pool. Heat is transferred to the RPCS at a plate and frame heat exchanger (1-LWPS-01A).
Material of Construction and Fabrication	The primary cooling system LWPS and PCLS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.2-3.
Shielding Depth	The top of the light water pool is located approximately 6 ft. above the top of the TSV.

Table 5a2.2-3 PCLS and LWPS Components
(Sheet 1 of 2)

Component	Description	Code/Standard
	PCLS	
1-PCLS-01A	PCLS cooler. Heat exchanger transfers heat from PCLS cooling loop to the RPCS. Plate and frame type.	ASME BPVC Section VIII (ASME, 2011)
1-PCLS-01T	PCLS cooling water tank. Provides thermal expansion protection, pump head pressure, and cooling loop water level monitoring.	ASME BPVC Section VIII (ASME, 2011)
1-PCLS-01P	PCLS cooling water pump. Circulates water along the cooling loop.	ANSI/HI 3.1-3.5 (ANSI/HI, 2008)
Instrumentation	Instruments to monitor the operation of the PCLS	ASME B40.100 (ASME, 2006); ASME B40.200 (ASME, 2008); ANSI N323D (ANSI, 2003); and other applicable codes and standards.
Piping Components	PCLS cooling loop piping, valves, in-line components.	ASME B31.3 (ASME, 2012)
	LWPS	
1-LWPS-01A	Light water pool cooler. Heat exchanger transfers heat from the LWPS cooling loop to the RPCS. Plate and frame type.	ASME BPVC Section VIII (ASME, 2011)
1-LWPS-01P	Light water pool cooling pump. Circulates water along the cooling loop.	ANSI/HI 3.1-3.5 (ANSI/HI, 2008)
Instrumentation	Instruments to monitor the operation of the LWPS	ASME B40.100 (ASME, 2006); ASME B40.200 (ASME, 2008); ANSI N323D (ANSI, 2003); and other applicable codes and standards.

Table 5a2.2-3 PCLS and LWPS Components
(Sheet 2 of 2)

Component	Description	Code/Standard
Piping Components	LWPS cooling loop piping, valves, in-line components.	ASME B31.3 (ASME, 2012)
	LWPS and PCLS Cleanup Components	
Pre-filter	Removes particulates greater than 3 to 5 microns from the PCLS/LWPS cooling water.	ASME BPVC Section VIII (ASME, 2011)
Ion Exchange Column	Column packed with resin to remove ionic species from the PCLS/LWPS cooling water.	ASME BPVC Section VIII (ASME, 2011)
Post-Filter	Removes particulates greater than 3 to 5 microns	ASME BPVC Section VIII (ASME, 2011)
Piping Components	Piping, valves, in-line components. Quick disconnect connections are included on the filters to make filter replacement a quick procedure.	ASME B31.3 (ASME, 2012)

Table 5a2.2-4 PCLS and LWPS System Interfaces

System	Interface Description
Radioisotope Process Cooling Water System (RPCS)	Interfaces at the 1-LWPS-01A and 1-PCLS-01A supply and return connections of the RPCS to remove heat from the primary cooling system loops during normal irradiation and shut down operations of each IU.
Uranyl Nitrate Conversion System (UNCS)	Interfaces at the cooling water purge lines of both cooling loops. In the event that either the PCLS or LWPS needs to be evacuated due to contamination, they may be purged to UNCS.
Light Water Pool and Primary Closed Loop Cooling Makeup System (MUPS)	Interfaces at the makeup water connections on the PCLS and LWPS to provide makeup water, when needed.
Neutron Driver Assembly System (NDAS)	The LWPS provides cooling to the target chamber.
Subcritical Assembly System (SCAS)	The LWPS and PCLS provide cooling to the SCAS.
Normal Electrical Power Supply System (NPSS)	The NPSS provides power to PCLS and LWPS cooling loop equipment and instrumentation.
TSV Reactivity Protection System (TRPS)	TRPS provides safety-related shut down of the IU neutron driver and dump of the TSV in the event the PCLS fails to provide heat removal from the IU or overcools the TSV.
Facility Instrument Air System (FIAS)	FIAS provides instrument air to PCLS/LWPS loop pneumatic control mechanisms.
TSV Process Control System (TPCS)	TPCS monitors and controls PCLS/LWPS loop actuators and instrumentation on valves and piping accessories.

5a2.3 SECONDARY COOLING SYSTEM

5a2.3.1 DESIGN BASIS

The secondary cooling system provides heat removal from the primary cooling system during normal TSV/IU operation and shut down. The secondary cooling system for the IUs is the RPCS, which also provides cooling water to the process systems.

This section focuses on the RPCS requirements with respect to the primary cooling system, which includes the LWPS and PCLS cooling loops, but discusses the other process systems the RPCS provides cooling to as well. There are eight IUs, each with an LWPS and PCLS cooling loop.

The RPCS provides cooling water to equipment within the RCA boundary in the facility. The RPCS is a closed loop cooling system that circulates cooling water to process system users within the RCA boundary and transfers the absorbed heat to the FCHS via a plate and frame heat exchanger within the RCA boundary. The RPCS is not a safety-related system. If flow in the RPCS is interrupted leading to temperature rise in the process systems, process equipment requiring cooling is shut down until normal operation flow and temperatures can be reestablished. Safety is not adversely affected for other process systems if RPCS cooling is lost.

See Figure 5a2.3-1 for the process flow diagram of the RPCS. Table 5a2.3-1 gives specifications for the system.

Heat is generated by the SCAS and NDAS target chamber and is absorbed by the LWPS and PCLS cooling loops for each IU. The NDAS utilizes RPCS cooling for other components located within the IU cell. The LWPS water circulates in a cooling loop that includes a heat exchanger where it interfaces with the RPCS. The PCLS cooling water circulates in a closed cooling loop that includes a heat exchanger where it interfaces with the RPCS.

The heat in the RPCS is transferred to the FCHS, where it is then dissipated to the environment.

5a2.3.2 PROCESS FUNCTIONS

The process functions of the RPCS are:

- Remove at a minimum [Proprietary Information] per IU of heat from the LWPS and at a minimum [Proprietary Information] per IU of heat from the PCLS during full-power irradiation. The total heat the RPCS removes from the eight IU LWPS and PCLS loops is approximately [Proprietary Information].
- Remove a total of [Proprietary Information] from RCA systems.
- Maintain physical integrity of system pressure boundary.
- Maintain water quality to reduce corrosion and scaling.
- Maintain higher pressure than the primary cooling systems.

5a2.3.3 TECHNICAL SPECIFICATION OPERATING PARAMETERS

There are no technical specification parameters identified for the RPCS.

5a2.3.4 RPCS COMPONENTS AND INTERFACES

The RPCS components are listed in Table 5a2.3-2, including design codes and standards. Figure 5a2.3-1 provides equipment reference.

The RPCS interfaces with the FCHS at the RPCS heat exchanger located within the RCA boundary. The FCHS cools the RPCS water to 60°F for supply to the RPCS usage points.

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

5a2.3.5 RPCS COOLING FUNCTIONS AND OPERATION

The pressure of the RPCS water is greater than the pressure of the primary cooling system to ensure that contaminants cannot be leaked into the RPCS water system if a plate or seal in the heat exchangers (1-LWPS-01A/1-PCLS-01A in Figure 5a2.2-2 and Figure 5a2.2-1) leaks. The pressure gradient between the RPCS and the primary cooling system loops prevents water from flowing into the RPCS. Pressure monitoring instrumentation (including low and/or high pressure alarms) in the RPCS verifies the pressure gradient is maintained. The primary cooling system (LWPS and PCLS) cooling loops are maintained at a lower pressure than the RPCS pressure at the heat exchanger.

The RPCS cooling loop piping and components are designed to prevent an uncontrolled release of radioactivity to the unrestricted environment. Refer to Chapter 11 for radiation protection, monitoring, and response guidelines.

Pressure, flow, and temperature instrumentation on the supply/return lines of the RPCS indicates a malfunction with an increase in pressure drop and low flow.

Isolation valves around the heat exchanger ensure that there is no contamination of the RPCS by primary coolant during maintenance activities.

Sampling and analysis of water from the RPCS loop is performed periodically to ensure radiological contaminants are below acceptable limits. If the system is found to be operating beyond safe levels, the system will be shut down and the contaminated water will be purified using ion exchange beds or purged to the uranyl nitrate conversion system (UNCS). Operators then inspect the malfunctioning equipment and remedy the issue accordingly. The RPCS cooling loop is refilled with FDWS water to continue normal operation.

Sampling and analysis of the water from the RPCS loop is also performed to ensure that the water quality requirements are being maintained. Maintaining water quality requirements ensures functional and safe operation in the RPCS by reducing damage done by corrosion and scaling. See Table 5a2.3-1 for RPCS water quality requirements.

During IU shut down, the RPCS loop remains active until the heat in the TSV has reached an acceptably low level. The amount of time that RPCS is active beyond IU shut down is determined during operations by temperature monitoring.

5a2.3.6 COOLING CONTROL

The heat removal provided by the RPCS loop to the two primary cooling system cooling loops (LWPS, 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 2-way control valve.

Further detail on the cooling control limitations will be provided in the FSAR.

5a2.3.7 LOSS OF COOLING

The primary cooling system and RPCS loops are active systems that require power to the circulation pumps and instrumentation to operate. The light water pool provides a passive engineered cooling method that absorbs fission decay heat produced after the neutron driver has been shut down.

Loss of cooling design basis accidents are discussed in Chapter 13.

5a2.3.8 COMPONENT FUNCTIONS AND LOCATIONS

The RPCS heat exchanger, pump, and associated components are located inside the RCA boundary at the FCHS interface. A RPCS head tank is located with the RPCS components to provide thermal expansion protection of the RPCS piping system. If the RPCS becomes contaminated with primary coolant, the following essential components ensure contamination is not inadvertently released to the environment:

- Floor drains within the RCA boundary drain to sumps (critically safe where necessary) to prevent leaked or spilled RPCS water from damaging equipment and contain the liquids.

- Makeup water to the RPCS cooling loop is provided by the FDWS. The makeup water connection is located upstream of the RPCS heat exchanger. Air-gap backflow prevention equipment is used at this connection to ensure that potentially contaminated water in the RPCS loop does not contaminate the FDWS.

- The secondary cooling system does not interface with the environment. The pressure of the RPCS is maintained below the pressure of the FCHS.

5a2.3.9 INSTRUMENTATION AND CONTROL

Pressure, flow, temperature, conductivity, and radiation detection instrumentation are included in the design of the RPCS to ensure operation within design conditions.

Pressure, flow, and temperature measurement instrumentation are placed on the RPCS loop. Setpoints ensure that operators are alerted when an operating condition is out of specification. Pressure, flow, and temperature conditions are monitored for the RPCS inlet and outlet to process system heat exchangers.

A conductivity analyzer is located near the RPCS heat exchanger (1-RPCS-01A) and pump (1-RPCS-01P) to detect the ionic level in the RPCS water. If the conductivity measurement reaches 2000 μmho/cm the operators are alerted to take clean-up action. This limits corrosion and scaling damage in the RPCS system.

Radiation instrumentation, including alarms, are located at the RPCS cooling water return connection at the RCA boundary to detect possible contamination of the RPCS cooling loop. If a leak is detected, individual sampling and monitoring is performed to determine the source.

The RPCS piping includes dual air-gap backflow prevention components at the interface with the FDWS. This prevents possibly contaminated RPCS water from coming in contact with the makeup water. The air-gap backflow prevention components help ensure the radiation dose-limiting ALARA guidelines in Chapter 11 are met.

5a2.3.10 RPCS OTHER USERS

The other process systems that require RPCS cooling water are listed below and are also listed in Table 5a2.3-3:

- TSV Off-Gas System (TOGS)
- Molybdenum Extraction and Purification System (MEPS)
- Uranyl Nitrate Conversion System (UNCS)
- Process Vessel Vent System (PVVS)
- Radioactive Liquid Waste Evaporation and Immobilization System (RLWE)
- Tritium Purification System (TPS)
- Neutron Driver Assembly System (NDAS)

The total heat duty for the RPCS in the SHINE facility is approximately [Proprietary Information], which includes RCA systems currently in the design.

Table 5a2.3-1 RPCS Specifications

Parameter	Nominal Value
RPCS Coolant Material	Water
RPCS Coolant Source	FDWS
RPCS Supply Conditions	60°F 30 to 50 psig RPCS-PCLS loop (1-PCLS-01A) flow rate: [Proprietary Information] RPCS-LWPS loop (1-LWPS-01A) flow rate: [Proprietary Information]
RPCS Return Conditions	Primary cooling system (LWPS/PCLS): 67°F 25-45 psig Other systems: 75°F 25-45 psig
Heat Exchanger Duty	PCLS (1-PCLS-01A): [Proprietary Information] per IU LWPS (1-LWPS-01A): [Proprietary Information] per IU See Subsection 5a2.3.2 for the total RPCS heat duty within the RCA boundary.
System Type	Supply and return cooling water closed loop that removes heat from the primary cooling system (LWPS, PCLS) and other process systems via plate and frame and other types of heat exchangers.
Material of Construction	RPCS components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.3-2.
Heat Dissipation w/ Relation to Environmental Factors	This system is not designed to dissipate heat to the environment.
RPCS Coolant Quality (IAEA, 2011)	Conductivity: <2000 μmho/cm pH: 6 to 8

Table 5a2.3-2 RPCS Components

Component	Description	Code/Standard
1-RPCS-01A	RPCS heat exchanger. Transfers heat from RPCS cooling loop to the FCHS. Plate and frame type.	ASME BPVC Section VIII (ASME, 2011)
1-RPCS-01T	RPCS expansion tank. Provides thermal expansion protection for the RPCS piping and components.	ASME BPVC Section VIII (ASME, 2011)
1-RPCS-01P	RPCS water pump. Circulates RPCS water along the cooling loop.	ANSI/HI 3.1-3.5 (ANSI/HI, 2008)
Piping Components	RPCS piping, valves, in-line components.	ASME B31.3 (ASME, 2012)
Instrumentation	Pressure, temperature, flow, and radiation instrumentation to monitor the operation of the RPCS.	ASME B40.100 (ASME, 2006); ASME B40.200 (ASME, 2008); ANSI N323D (ANSI, 2003); and other applicable codes and standards.

Table 5a2.3-3 RPCS Interfaces

System	Interface Description
Primary Cooling System (LWPS/PCLS)	Interfaces at the 1-PCLS-01A and 1-LWPS-01A supply and return connections of the PCLS and LWPS cooling loops to remove heat from the SCAS and target chamber during normal operation and shut down.
TSV Off-Gas System (TOGS)	Interfaces at the 1-TOGS-01A and 1-TOGS-02A supply and return connections of the TOGS to condense water vapor and remove the exothermic reaction heat from recombiner beds.
Molybdenum Extraction and Purification System (MEPS)	Interfaces at the condenser unit supply and return connections of 1-MEPS-01A to condense the evaporation gas from the rotary evaporator.
Uranyl Nitrate Conversion System (UNCS)	Interfaces at the 1-UNCS-02A, 1-UNCS-04A, 1-UNCS-05A, and 1-UNCS-06A supply and return connections. Removes the heat generated in 1-UNCS01T from the uranyl nitrate conversion reaction. Cools the recycled target solution being transferred to 1-UNCS-09T. Condenses the overheads from 1-UNCS-07T and 1-UNCS-08T. Also interfaces at RPCS purge line.
Process Vessel Vent System (PVVS)	Interfaces at the 1-PVVS-01A supply and return connections. Cools the recycle loop of 1-PVVS-01T.
Radioactive Liquid Waste Evaporation System (RLWE)	Interfaces at the 1-RLWE-02A and 1-RLWE-03A supply and return connections. Condenses the overheads from 1-RLWE-02T.
Facility Chilled Water Supply and Distribution System (FCHS)	Interfaces at the 1-RPCS-01A supply and return connections. Transfers heat from the RPCS to the FCHS so it can be released to the environment outside of the RCA boundary.
Normal Electrical Power Supply System (NPSS)	The NPSS provides power to RPCS equipment and instrumentation.
Tritium Purification System (TPS)	Interfaces at the 1-TPS-01A supply and return connections. Cools the TPS glovebox atmosphere.
Facility Instrument Air System (FIAS)	FIAS provides instrument air to RPCS pneumatic control mechanisms.
Facility Integrated Control System (FICS)	FICS monitors and controls RPCS actuators and instrumentation on valves and piping accessories.
Facility Demineralized Water System (FDWS)	The FDWS provides makeup water to the RPCS.
Neutron Driver Assembly System (NDAS)	Interfaces with the NDAS within the IU.

5a2.4 PRIMARY COOLANT CLEANUP

5a2.4.1 DESIGN BASIS

The primary coolant cleanup is not an independent system, but is part of the PCLS and LWPS. The purpose of primary coolant cleanup is to maintain the required water quality limits of the primary cooling system coolant.

Maintaining the required water quality limits corrosion damage and scaling to the PCLS, LWPS, SCAS, and NDAS target chamber components. These components include the primary coolant barrier, the TSV, light water pool, and associated components. Due to the nature of the target solution, the SCAS does not utilize cladding. The primary coolant cleanup also removes activation products and other radioactive contaminants from the primary PCLS/LWPS coolant to maintain radiation exposures ALARA. See Subsection 11.1.3 for ALARA guidelines.

The TSV is constructed of zircaloy-4, an alloy of zirconium that offers exceptional corrosion resistance under irradiation and offers a very low neutron absorption cross section. Zircaloy-4 is widely used throughout the nuclear industry where corrosion resistance and neutron economy are important (such as in fuel cladding).

The design of the primary coolant cleanup system follows design recommendations from the International Atomic Energy Agency (IAEA) report (NP-T-5.2) on good practices for water quality management in research reactors (IAEA, 2011). This report includes recommended water quality limits and design for research reactor cooling water cleanup systems.

See Section 5a2.2 for the detailed discussion of the primary cooling system.

5a2.4.2 PROCESS FUNCTIONS

The following are the process functions of the primary coolant cleanup loops:

- Maintain water quality to reduce corrosion and scaling.
- Limit concentrations of particulate and dissolved contaminants that could be made radioactive by neutron irradiation within ALARA guidelines.

5a2.4.3 PROCESS FLOW

See Figure 5a2.4-1 for the process flow of the primary coolant cleanup loops on the PCLS and LWPS. The LWPS components are shown in Figure 5a2.4-1, but the layout for the PCLS is the same.

In Figure 5a2.4-1, streams 0803 and 0804 represent the PCLS/LWPS cooling loop. The cleanup loop is shown as stream 0807. The cleanup loop includes a conductivity analyzer to measure the ionic content in the PCLS/LWPS cooling loop, a pre-filter (1-LWPS-01F-A-H) to remove particulates greater than approximately 3 to 5 microns, an ion exchange column (1-LWPS-01D-A-P) to remove ionic species, a post-filter (1-LWPS-02F-A-H) to remove any particles that leave the column resin packing greater than approximately 3 to 5 microns. The

cleanup loop flow rate is operated at 1 to 10 percent of the associated PCLS/LWPS cooling loop flow rate to provide constant water treatment. A standby ion exchange column is included so that an operator may switch flow to it in the event the column in service becomes unable to remove ionic species from the coolant.

5a2.4.4 SYSTEM SPECIFICATIONS

See Tables 5a2.2-1 and 5a2.2-2 for specifications of the primary coolant cleanup system. The specifications in Tables 5a2.2-1 and 5a2.2-2 ensure normal operation of the primary coolant cleanup system without adversely affecting normal operation of other associated systems. The primary coolant cleanup system specifications are chosen to limit corrosion damage and scaling in the PCLS, LWPS, and IU-related equipment.

There are no technical specification parameters identified for the PCLS or the LWPS cleanup loops.

5a2.4.5 CLEANUP LOOP CONTROL AND INSTRUMENTATION

The cleanup loop components are located in the primary cooling system enclosures located directly adjacent to the IU cells.

The instrumentation discussed in this section continuously monitors the associated PCLS/LWPS water with 1 to 10 percent of the cooling loop flow rate directed to the cleanup loop.

Conductivity instrumentation, upstream of the filter, measures the conductivity within the PCLS/LWPS. Differential pressure instrumentation connected to the inlets and outlets of the filters measure the pressure drop across each filter. pH of the PCLS/LWPS coolant is monitored. Flow and pressure indication is also included on each cleanup loop to monitor proper function of the cleanup loops (i.e. no leaks/malfunctions).

5a2.4.6 CLEANUP LOOP COMPONENTS

See Table 5a2.2-3 for the list of primary coolant cleanup components and their functions.

The primary coolant cleanup components are designed and fabricated in accordance with the codes and standards listed in Table 5a2.2-3.

5a2.4.7 MAINTENANCE AND COOLANT TESTING

Filters are replaced in accordance with manufacturer recommendations and ALARA practices. Ion exchange columns are regenerated or replaced in accordance with manufacturer recommendations.

Sampling and testing of the PCLS/LWPS water is done periodically to ensure that the primary coolant cleanup system components and instrumentation are working properly to meet the primary coolant water quality requirements listed in Tables 5a2.2-1 and 5a2.2-2 and to monitor radioactive contaminants that could indicate a PSB leak.

Isolating the cleanup loop from the associated PCLS/LWPS cooling loop for maintenance purposes does not disrupt IU operation or prevent safe IU shut down.

5a2.5 PRIMARY COOLANT MAKEUP WATER SYSTEM

5a2.5.1 DESIGN BASIS

The primary coolant makeup water system provides makeup water to the PCLS and LWPS cooling loops and is called MUPS.

Operational coolant loss in the PCLS and LWPS occurs gradually from radiolysis and evaporation (evaporation in LWPS only). Coolant loss may also occur from off-normal events such as leaks and PCLS/LWPS coolant purges to UNCS. The coolant may be purged if radioactive contaminants are detected in the coolant beyond operational limits.

5a2.5.2 PROCESS FUNCTIONS

The process function of the MUPS is to provide controlled makeup water to the PCLS and LWPS.

5a2.5.3 PROCESS FLOW

See Figure 5a2.2-1 for the MUPS connection to each of the LWPS cooling loops (eight total). The MUPS makeup water supply line includes an air-gap backflow prevention device (not shown on Figure 5a2.2-1) to ensure that LWPS water does not come in contact with MUPS water. This prevents possible contamination of the MUPS.

See Figure 5a2.2-2 for the flow diagram sketch of the MUPS connection to each of the PCLS cooling loop tanks (eight total). The MUPS makeup water supply line includes an air-gap backflow prevention device (not shown on Figure 5a2.2-2) to ensure that PCLS water does not come in contact with MUPS water. This prevents possible contamination of the MUPS.

5a2.5.4 DESIGN SPECIFICATIONS

The MUPS water is supplied from the FDWS to provide pretreated water to the PCLS and LWPS. See Table 5a2.5-1 for specifications of the MUPS water.

MUPS water meets the quality requirements of the PCLS and LWPS and requires no further treatment before being added to the PCLS and LWPS.

5a2.5.5 MUPS CONTROL AND INSTRUMENTATION

MUPS makeup water is added remotely to the PCLS and LWPS loops, as needed, to avoid disrupting IU operations when there are no leaks or malfunctions occurring in the PCLS/LWPS. If leaks or malfunctions are occurring in the PCLS/LWPS that require significant amounts of makeup water or pose a safety risk to the surrounding area, the IU is shut down so the operators can take corrective action in accordance with Chapter 11 guidelines.

The temperature of the MUPS water is between 70 and 80°F in order to limit thermal changes to the PCLS and LWPS.

The pressure of the MUPS is greater than the PCLS and LWPS loops so that PCLS/LWPS coolant cannot flow into the MUPS piping when makeup water is being added. An air-gap backflow prevention device ensures that PCLS/LWPS coolant does not flow into the MUPS piping.

The flow rate of the MUPS water into the PCLS/LWPS is set depending on the required makeup amount in order to not overfill the PCLS tank or LWPS pool. Liquid level monitoring instrumentation on the light water pool and PCLS tank provide operators with normal liquid levels for each PCLS/LWPS. The flow rate is set remotely by opening the MUPS inlet valve. The MUPS is not designed to provide a rapid, total replacement flow rate of the LWPS or PCLS, but it is able to maintain the operating PCLS and LWPS volumes and account for partial coolant losses. The flowrate for the MUPS system is listed in Table 5a2.5-1.

To prevent overfilling the PCLS and LWPS, liquid level instrumentation is included to automatically stop MUPS flow into the PCLS/LWPS loops if high liquid level is reached. The level instrumentation also actuates an alarm to alert operators to take remedial action in case the MUPS water continues to flow to the PCLS/LWPS (e.g., malfunctioning MUPS inlet valve).

5a2.5.6 MUPS COMPONENTS

The MUPS components consist of the piping, flow controllers, valves, and associated components between the FDWS and PCLS/LWPS interfaces of the MUPS. The MUPS components include instrumentation discussed in Subsection 5a2.5.5 and the air-gap backflow prevention devices. MUPS piping and piping components are designed to follow ASME B31.3 standards (ASME, 2012).

The pump(s) and pretreatment equipment (pH, conductivity) are included with the FDWS to deliver makeup water to the MUPS with the required pressure and water quality limits.

The FDWS components are located outside of the RCA boundary with piping connections to the MUPS lines within the RCA boundary that run to the LWPS and PCLS connections.

Table 5a2.5-1 MUPS Specifications

Parameter	Nominal Value
MUPS Supply Connections	16 total MUPS distribution points in the facility (8 for PCLS, 8 for LWPS)
MUPS Water Quality	Conductivity: <5 μmho/cm pH: 5.5 to 7.5 These values are based on recommended water quality limits from IAEA NP-T-5.2, Chapter 9 (IAEA, 2011).
MUPS Source	FDWS
MUPS Supply Conditions	Temperature: 70 to 80°F Flow rate: 0 to 20 gpm Pressure: 30 to 50 psig

5a2.6 NITROGEN-16 CONTROL

There is no independent N-16 control system. The radiation dose from N-16 is mitigated by the IU cell walls and shielding around the PCLS/LWPS components in the primary cooling enclosures and the administrative controls defined by the radiation protection program.

5a2.7 AUXILIARY SYSTEMS USING PRIMARY COOLANT

SHINE facility IU auxiliary systems do not utilize the primary cooling system for cooling duty. Therefore, this section does not apply to the SHINE facility.

5a2.8 REFERENCES

ANSI/HI, 2008. Rotary Pumps (A109), 3.1-3.5, American National Standards Institute, January 1, 2008.

ASME, 2011. Boiler & Pressure Vessel Code - Rules for Construction of Pressure Vessels, Section VIII, American Society of Mechanical Engineers, July 1, 2011.

ASME, 2012. Code for Pressure Piping, B31.3-2012, American Society of Mechanical Engineers, January 10, 2013.

IAEA, 2011. NP-T-5.2, Good Practices for Water Quality Management in Research Reactors and Spent Fuel Storage Facilities, International Atomic Energy Agency, July 1, 2011.

5b RADIOISOTOPE PRODUCTION FACILITY COOLING SYSTEMS

In addition to providing secondary cooling function for the irradiation facility, the RPCS also provides cooling to the radioisotope production facility. See Section 5a2.3.