5.0 COOLING SYSTEMS

The principal purpose of the cooling systems is to safely remove fission and decay heat from the target solution and dissipate it to the environment under normal and accident conditions. Cooling systems, including auxiliary and subsystems that use and contribute to the heat load of the primary or secondary cooling systems, should be shown to safely remove and transfer heat to the environment from all significant heat sources identified in the SHINE Medical Technologies, LLC (SHINE, the applicant) final safety analysis report (FSAR). The final design of the cooling systems is based on interdependent parameters, including thermal power level, type and form of special nuclear material, neutronic physics, and radiation shielding.

This chapter of the SHINE operating license application safety evaluation report (SER) describes the review and evaluation of the U.S. Nuclear Regulatory Commission (NRC, the Commission) staff of the final design of the SHINE irradiation facility (IF) and radioisotope production facility (RPF) cooling systems, as presented in Chapter 5, “Cooling Systems,” of the SHINE FSAR and supplemented by the applicant’s responses to staff requests for additional information (RAIs).

5a Irradiation Facility Cooling Systems

SER section 5a, “Irradiation Facility Cooling Systems,” provides an evaluation of the final design of SHINE’s IF cooling systems as presented in SHINE FSAR sections 5a2, “Irradiation Facility Cooling Systems,” and 5b, “Radioisotope Production Facility Cooling Systems,” within which the applicant described the primary closed loop cooling system (PCLS), radioisotope process facility cooling system (RPCS), process chilled water system (PCHS), primary closed loop cooling system cleanup side stream, facility demineralized water system (FDWS), nitrogen-16 (N-16) control, and auxiliary systems using primary coolant.

5a.1 Areas of Review

The NRC staff reviewed SHINE FSAR section 5a2 against applicable regulatory requirements, using appropriate regulatory guidance and acceptance criteria, to assess the sufficiency of the final design of the SHINE IF cooling systems.

SHINE FSAR section 5b describes the SHINE cooling systems as integrated throughout the facility as described in SHINE FSAR section 5a2. Specifically, SHINE FSAR section 5a2.3, “Radioisotope Process Facility Cooling System,” describes that the RPCS serves as a secondary cooling system for the irradiation units (IUs) in the IF and provides cooling to the RPF. Therefore, the areas of review related to the RPCS presented in this section are applicable to both the IF and the RPF.

5a.2 Summary of Application

As stated above and described in SHINE FSAR sections 5a2.3 and 5b, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF. Therefore, the summary provided below applies to both the IF and the RPF.

The IF cooling systems consist of a primary cooling system and a secondary cooling system. The primary cooling system comprises the PCLS and the light-water pool system (LWPS). The

PCLS and the LWPS provide the heat removal to the IU equipment that is submerged within the light-water pool. There are eight IUs and each of the IUs includes a PCLS and a LWPS. The secondary cooling system is referred to as the RPCS. The RPCS removes heat from the PCLS/LWPS and transfers it to the facility chilled water supply system (FCHS). The RPCS is a closed loop system that provides cooling water to all of the process areas within the radiologically controlled area (RCA). The thermal partitions between the PCLS/LWPS and the RPCS cooling systems are the heat exchangers at the system interfaces. The primary coolant cleanup loops provide treatment of the PCLS and the LWPS coolant to meet water quality limits. The FDWS provides makeup water to the PCLS, RPCS, FCHS, molybdenum extraction and purification system (MEPS), and LWPS. In addition to providing a secondary cooling function for the IF, the RPCS also provides cooling to the RPF. While the PCLS uses a delay tank to reduce N-16, there is no independent N-16 control system.

5a.3 Regulatory Requirements and Guidance and Acceptance Criteria

The NRC staff reviewed SHINE FSAR Chapter 5 against the applicable regulatory requirements, using appropriate regulatory guidance and acceptance criteria, to assess the sufficiency of the bases and the information provided by SHINE for the issuance of an operating license.

5a.3.1 Applicable Regulatory Requirements

The applicable regulatory requirements for the evaluation of the SHINE IF cooling systems are as follows:

- Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.34, “Contents of applications; technical information,” paragraph (b), “Final safety analysis report.”
- 10 CFR 50.36, “Technical specifications.”
- 10 CFR 50.40, “Common standards.”
- 10 CFR 50.57, “Issuance of operating license.
- 10 CFR Part 20, “Standards for Protection Against Radiation.”

5a.3.2 Applicable Regulatory Guidance and Acceptance Criteria

In determining the regulatory guidance and acceptance criteria to apply, the NRC staff used its technical judgment, as the available guidance and acceptance criteria were typically developed for nuclear reactors. Given the similarities between the SHINE facility and non-power research reactors, the staff determined to use the following regulatory guidance and acceptance criteria:

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

- NUREG-1537, Part 2, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Standard Review Plan and Acceptance Criteria,” issued February 1996.

- “Final Interim Staff Guidance Augmenting NUREG-1537, Part 1, ‘Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content,’ for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors,” dated October 17, 2012.

- “Final Interim Staff Guidance Augmenting NUREG-1537, Part 2, ‘Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Standard Review Plan and Acceptance Criteria,’ for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors,” dated October 17, 2012.

As stated in the interim staff guidance (ISG) augmenting NUREG-1537, the NRC staff determined that certain guidance originally developed for heterogeneous non-power research and test reactors is applicable to aqueous homogenous facilities and production facilities. SHINE used this guidance to inform the design of its facility and to prepare its FSAR. The staff’s use of reactor-based guidance in its evaluation of the SHINE FSAR is consistent with the ISG augmenting NUREG-1537.

As appropriate, the NRC staff used additional guidance (e.g., NRC regulatory guides, Institute of Electrical and Electronics Engineers (IEEE) standards, American National Standards Institute/American Nuclear Society (ANSI/ANS) standards, etc.) in the review of the SHINE FSAR. The additional guidance was used based on the technical judgment of the reviewer, as well as references in NUREG-1537, Parts 1 and 2; the ISG augmenting NUREG-1537, Parts 1 and 2; and the SHINE FSAR. Additional guidance documents used to evaluate the SHINE FSAR are provided as references in appendix B, “References,” of this SER.

5a.4 Review Procedures, Technical Evaluation, and Evaluation Findings

The NRC staff performed a review of the technical information presented in SHINE FSAR sections 5a2 and 5b, as supplemented, to assess the sufficiency of the final design of SHINE’s IF cooling systems for the issuance of an operating license. The sufficiency of the final design is determined by ensuring that it meets applicable regulatory requirements, guidance, and acceptance criteria, as discussed in section 5a.3, “Regulatory Requirements and Guidance and Acceptance Criteria,” of this SER. The findings of the staff review are described in section 5a.5, “Review Findings,” of this SER.

As described in SHINE FSAR sections 5a2.3 and 5b, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF.

5a.4.1 Summary Description

The NRC staff evaluated the sufficiency of the summary description of the SHINE IF cooling systems, as presented in SHINE FSAR section 5a2.1, “Summary Description,” using the guidance and acceptance criteria from section 5.1, “Summary Description,” of NUREG-1537, Parts 1 and 2, and section 5a2.1, “Summary Description,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

SHINE FSAR section 5a2.1 states that the IF cooling systems safely remove the fission and decay heat from the target solution and dissipate it to the environment. SHINE FSAR section 5a2.1 further states that the cooling systems in the facility consists of a PCLS, RPCS, and PCHS. The SHINE FSAR describes the PCLS as a closed loop water system that rejects heat to the RPCS, which rejects heat to the PCHS, then to the environment using air-cooled chillers. The RPCS, an intermediate chilled water system, rejects heat to the PCHS. The PCHS, a closed chilled loop rejects heat to the atmosphere using air-chillers.

The NRC staff finds that the principal features of the primary and secondary cooling systems are summarized in SHINE FSAR section 5a2.1. The staff notes that the primary and secondary cooling systems are closed cooling systems using water as a coolant to transfer heat generated in the target solution vessel (TSV) to the environment by the use of air-chillers. Because the principal features of the primary and secondary cooling systems are adequately described in SHINE FSAR section 5a2.1, the staff finds that the summary description of the facility cooling systems meets the acceptance criteria in NUREG-1537, Part 2 for the issuance of an operating license.

5a.4.2 Primary Cooling System

The NRC staff evaluated the sufficiency of the final design of SHINE's primary cooling system, as presented in SHINE FSAR section 5a2.2, "Primary Closed Loop Cooling System," in part, by reviewing the design basis, PCLS process functions, system process and safety functions, proposed technical specifications, primary cooling system components and interfaces, PCLS cooling functions and operation, LWPS cooling functions and operation, instrumentation and sampling, secondary cooling system interaction, and radiation exposure protection using the guidance and acceptance criteria from section 5.2, "Primary Coolant System," of NUREG-1537, Parts 1 and 2, and section 5a2.2, "Primary Cooling System," of the ISG augmenting NUREG-1537, Parts 1 and 2.

5a.4.2.1 Thermal-Hydraulic Design

As described in SHINE FSAR Chapter 4a2, "Irradiation Facility Description," the TSV of an IU is an annular pressure vessel that contains the target solution during the irradiation process. During irradiation, heat is generated in the target solution. The heat generation is volumetric and nonuniform. The highest generation rates are predicted to be towards the center of the target solution. During irradiation, the heat transfer mechanism from the target solution to the walls of the TSV and to the PCLS is a combination of temperature-driven natural convection of the bulk solution and bubble-driven convection by the flow of gas bubbles in the target solution. Radiolysis of the water in the target solution causes volumetric generation of hydrogen and oxygen bubbles. These bubbles flow upwards through the target solution to the surface of the solution, circulating the solution and enhancing the heat transfer. The heat transferred to the PCLS is carried away by forced external convection of the primary cooling water supplied by the PCLS. The PCLS is discussed in section 5a.4.2.7 of this SER.

During Mode 2 (Irradiation Mode - Operating mode, neutron driver active), with the exception noted below, the PCLS flow rate must be above the minimum required flow rate to ensure sufficient forced convection. In Mode 2, the thermal-hydraulic design allows for short periods (up to 3 minutes) without forced cooling water flow from the PCLS when there is no accelerator output. This allows for time to recover from potential cooling system transients without the necessity of dumping target solution from the TSV to the dump tank. During this time, the

system operates with natural convection cooling water flow. During Mode 1 (Startup Mode - Filling the TSV), no PCLS forced flow is required to maintain operating limits of the target solution. During Mode 3 (Post-Irradiation Mode - TSV dump valves open), no PCLS forced flow is required as the target solution is transferred to the TSV dump tank, and cooling of the solution is provided through natural convection to the LWPS. The TSV dump tank is discussed in section 5a.4.2.3 of this SER.

The applicant performed thermal-hydraulic and heat transfer calculations based on best estimate analytical methods employing thermal-hydraulic correlations, using conservative assumptions, as discussed in the following sections of this SER. Limiting core conditions were assumed in the thermal-hydraulic analysis of the TSV and the TSV dump tank. No credit was taken for heat removal by the TSV off-gas system (TOGS). This is a conservative assumption because the heat transfer to TOGS will reduce the average and peak temperatures of the target solution.

Heat Removal Systems

The SHINE facility thermal-hydraulic design includes systems that provide heat removal from the subcritical assembly during normal irradiation and shutdown operations. These systems include the PCLS and the LWPS for each IU. The TSV rejects heat through the inner shell, the outer shell, and the internal interfaces between the TSV and PCLS. The systems that are credited for the heat removal analysis are described below.

Primary Closed Loop Cooling System

The PCLS removes up to 137.5 kilowatts (kW) of heat by forced convection from a single TSV during full-power IU operation. The PCLS also removes up to 20 kW of heat by forced convection from a single neutron multiplier during full-power IU operation. There are eight PCLSs in the facility, and each PCLS is separate and independent for each IU. The PCLS circulates deionized water in the upward direction through the TSV along the outside of the TSV walls during normal operation. The heat absorbed by PCLS water is transferred to the RPCS through a heat exchanger. The RPCS is discussed in section 5a.4.3.1 of this SER. The PCLS removes approximately 98 percent of TSV fission power when assuming no heat removal by the TOGS. The PCLS is discussed in more detail in section 5a.4.2.6 of this SER.

Light Water Pool System

The LWPS contains no forced cooling components. In Mode 3, the LWPS performs direct cooling of the TSV dump tank by natural convection within the dump tank and natural convection of the pool water. The LWPS is expected to remove 100 percent of the decay thermal power (i.e., heat) from the TSV dump tank without boiling water in the LWPS or inside the dump tank. The applicant designed the system to prevent boiling of the target solution either within the TSV or the TSV dump tank.

The LWPS does not provide direct cooling of the TSV or neutron multiplier. Due to the radiation shielding provided by the LWPS, power is deposited into the pool by long range radiation from the TSV, neutron multiplier, and neutron driver. Up to 2.3 kW of heat is estimated to be deposited in the pool during full-power IU operation. There are no heat exchangers that cool the LWPS. The pool is heated to slightly above PCLS temperature from radiation heating, and heat is primarily transferred from the pool through piping and component walls to the PCLS cooling water. The pool is maintained within the temperature range of 50 degrees Fahrenheit (°F)

(10 degrees Celsius (°C)) to 95°F (35°C) during normal operation, and the pool temperature is monitored. If PCLS cooling is lost, the irradiation process is shut down due to the TSV reactivity protection system (TRPS) initiating an IU Cell Safety Actuation on low PCLS flow or high PCLS temperature. Heat transfer also occurs through evaporation to the IU cell atmosphere and conduction through the surrounding concrete. However, these two mechanisms are not credited in the analysis, which is conservative because these mechanisms will lower actual pool temperatures, which the NRC staff finds to be acceptable. The fraction of heat removed by the LWPS is estimated to be about 2 percent of the thermal power of the TSV.

In the event of a failure of the PCLS forced cooling function, the target solution is drained from the TSV to the TSV dump tank and the large thermal mass of the LWPS water provides decay heat removal capacity and cools the target solution. As a result, the temperature in the LWPS is calculated not to exceed a specific temperature level after a certain decay heat period assuming that the pool is at its minimum allowable level for accident conditions. The LWPS is expected to remove decay heat from the target solution in the TSV dump tank after the target solution has been irradiated, prior to its transfer to the extraction cell. For calculating LWPS heatup in Mode 3, the PCLS is assumed to not be operating. This is a conservative assumption because the PCLS provides cooling to the pool and assuming it is not operating will result in higher pool and target solution temperatures. The NRC staff evaluation of the LWPS heatup analysis is provided in section 5a.4.2.4 of this SER.

The LWPS liner is designed as Seismic Category I and is expected to remain intact during normal operation, as well as during a design-basis earthquake and design-basis accident events. Penetrations through the LWPS liner are above the minimum required water level. Because the combination of the above design criteria will ensure that the minimum required water level can be readily maintained, the NRC staff finds this acceptable.

5a.4.2.2 Target Solution Vessel

The TSV is an annular vessel with cooling capability. The TSV transfers heat through the TSV inner shell, the TSV outer shell, and the TSV inner structures to the PCLS. Among these surfaces, approximately 50 percent of the heat is expected to be transferred through the inner and outer shells.

The PCLS removes heat directly from the surfaces mentioned above during normal operation and transients. Cooling water flows up from the lower plenum of the subcritical assembly support structure (SASS), past the TSV and neutron multiplier, and collects in the SASS upper plenum before returning to the PCLS heat exchanger. Three cooling channels are formed by the SASS, TSV, neutron multiplier, and tritium target chamber. Cooling channel 1 (CC1) is the annular gap between the tritium target chamber and the neutron multiplier inner shell exterior surface. Cooling channel 2 (CC2) is the annular gap between the TSV and neutron multiplier. Cooling channel 3 (CC3) is the annular gap between the TSV and the SASS inner baffle. Only CC2 and CC3 cool the TSV. There is no coupling between cooling flows except at the SASS upper and lower plenums. The PCLS is not designed to cool the tritium target chamber because the target chamber is internally cooled by forced cooling water supplied by the neutron driver assembly system through an outer cooling jacket.

The thermal-hydraulic analysis was based on assuming the lowest allowable PCLS flow rate and the maximum allowable PCLS cooling water temperature of 77°F (25°C). These limits are protected by the TRPS IU Cell Safety Actuation setpoints. The TSV headspace pressure is maintained slightly below atmospheric pressure. The pressure over the target solution in the

TSV is normally between -2 pounds per square inch gage (psig) and 0 psig. Because the primary cooling water temperature is maintained well below the boiling point at atmospheric pressures, the pressure profiles of the cooling water in the flow channels are not important to safety. The total cooling water flow rate and the inlet temperature are the principal variables of importance for heat transfer. These variables are monitored by the TRPS.

The TSV is maintained at a nominal 120°F (50°C) during irradiation, which is well below the boiling point of water, even at a pressure slightly below atmospheric. No plating out of chemicals is expected from boiling because no boiling occurs in the TSV. Evaporation of the target solution and collection of solid salts on the TSV walls at the liquid surface is postulated; however, this does not affect the heat transfer as this will be above the liquid surface. Potential precipitates are not expected to have significant impact on heat transfer in the TSV. Small amounts of precipitates could form in the target solution; however, because the heat transfer surfaces are vertical, collection of settled precipitates is reduced.

The applicant analyzed two scenarios in the event of a loss of off-site power (LOOP). For short duration LOOP events (nominally less than 3 minutes), the target solution normally remains in the TSV. The PCLS pumps will not function on a LOOP and PCLS flow will be lost. For long duration LOOP events (nominally greater than 3 minutes), the target solution is dumped to the TSV dump tank. In the dump tank, the LWPS serves as the passive decay heat sink for the target solution. The applicant performed bounding analyses for the natural convection cooling in the TSV dump tank once the target solution is transferred to the TSV dump tank. The highest target solution temperature within the TSV dump tank is predicted to be less than 194°F (90°C), as shown in SHINE FSAR figure 4a2.7-4, “Target Solution Vessel Dump Tank Bounding Temperature Profile.” A minimum water level in the LWPS is required such that it can safely remove decay heat from the TSV dump tank. The NRC staff evaluation of the target solution heat-up analysis inside the TSV dump tank is provided in section 5a.4.2.4 of this SER.

5a.4.2.3 Target Solution Vessel Dump Tank

Under normal circumstances, the target solution heat will decay within the TSV dump tank for a period of time after irradiation and prior to processing. Additionally, when the PCLS is not available, the target solution is dumped from the TSV into the TSV dump tank and decay heat is passively removed by the LWPS water surrounding the TSV dump tank. During certain abnormal circumstances, the target solution could be allowed to remain within the TSV dump tank for an extended period of time. Such circumstances could include an unplanned shutdown of the IU.

The TSV dump tank is a horizontal annular tank, submerged in the LWPS water. It is only partially filled with the target solution when the solution is transferred to the dump tank. The NRC staff’s review of the TSV dump tank design finds that the dump tank geometry and dimensions enhance the heat transfer surface area in order to facilitate decay heat removal from the target solution by the natural convection heat transfer process to the LWPS water through the inner and outer shell surfaces of the dump tank. Because the described design supports decay heat removal as described in the following section of this SER, the staff finds it acceptable.

The NRC staff evaluation of the methodology and the assumptions used for passive decay heat removal from the TSV dump tank and safe shutdown of the SHINE facility is discussed in section 5a.4.2.4 of this SER.

5a.4.2.4 Thermal-Hydraulic Calculation and Testing

Heat flux along the cooling surfaces was calculated using the limiting core condition. A correlation-based methodology was used for safety-related calculations of the TSV thermal-hydraulics. The methodology included a heat transfer correlation developed based on test data applicable to the SHINE facility and accounted for relevant engineering tolerances and uncertainties. This heat transfer correlation was used for heat transfer between the target solution and the walls of the PCLS cooling channels.

For the PCLS cooling channel flow, a heat transfer correlation for turbulent internal forced convection was used. The NRC staff compared the results of this correlation to other heat transfer correlations for turbulent internal forced convection and found that SHINE's correlation conservatively underestimated heat transfer. Additionally, the staff performed confirmatory analysis to evaluate whether uncertainty in this correlation might impact the evaluation of PCLS performance and concluded that other conservatisms in SHINE's evaluation offset potential variation in heat transfer due to uncertainty in the heat transfer coefficient. Based on the above information, the staff finds the use of this correlation to be acceptable.

<u>TSV Tests</u>

For the heat transfer process inside the TSV, tests were performed at the University of Wisconsin – Madison to develop a heat transfer correlation for the unique condition that exists inside the TSV involving volumetric heat generation in the target solution with bubble formation, cooled walls, and the TSV cooling arrangement. The applicant reviewed the existing correlations in the published literature. Volumetric heat generation was approximated using cartridge heaters. Short and long cartridge heaters were used to study the sensitivity of the power density. Volumetric bubble generation was approximated by injecting a roughly uniform sheet of bubbles at the base of the vessel. The cooled vessel walls were made of stainless steel, and aluminum heat exchangers were applied to the outer surface of these walls to simulate the cooled wall condition. A water and magnesium sulfate solution was used as a uranyl sulfate target solution surrogate in the experiments. The magnesium sulfate heat transfer properties were found to be comparable to that of uranyl sulfate.

The experimental results demonstrated that thermal stratification of the surrogate target solution was negligible. Bulk fluid was assumed to rise from the bottom of the TSV to the target solution surface with downward recirculation along the cold walls, similar to the chimney effect. The velocity of the upward flow was estimated based on the conservation of mass principle and the calculation of the downward flow rate along the cold walls. The downward flow rate was calculated based on the boundary layer characteristic velocity and the fully developed thickness of the target solution boundary layer. A flat plate approximation was assumed. A transit time was calculated based on the distance from the bottom of the TSV to the target solution surface and the velocity of the upward flow. The total temperature rise was calculated based on the power density in the control volume, the transit time, the solution heat capacity, and the solution mass density. Finally, the peak temperature was determined by adding the total temperature rise to the average temperature. Adding the total temperature rise to the average temperature is conservative because some of the temperature rise will occur at temperatures below the average temperature. The NRC staff finds that this approach to developing this heat transfer correlation is technically sound and consistent with current engineering practice. Further, the staff concludes that the parameters of the SHINE facility are within the range of parameters for which this correlation is valid and that this correlation is applicable to the SHINE facility.

Calculational Results – Normal Operations

The calculational results based on the above methodology show that the peak target solution temperature in the TSV was less than 194°F (90°C), which provides reasonable assurance that no significant boiling is expected to occur in the TSV. Furthermore, the bulk target solution temperature in the TSV was less than 176°F (80°C), which is an assumption of the passive decay heat removal and safe shutdown calculation discussed in the "Calculational Results – Passive Decay Heat Removal and Safe Shutdown" section of this SER.

Section 4a2.6, "Thermal-Hydraulic Design," of the ISG augmenting NUREG-1537, Part 2 states that the criteria for the thermal-hydraulic design should include that there should be no coolant flow instability in any cooling coil that could lead to a significant decrease in cooling, and that the departure from nucleate boiling (DNB) ratio should be no less than 2.0 along any cooling coil. To address this guidance, the applicant described that the PCLS cools the external surfaces of the neutron multiplier which contains natural uranium. Calculations performed for the worst-case power transient scenario in the neutron multiplier determined that the DNB ratio for the cooling surface is 4.8. The NRC staff finds that this meets the ISG acceptance criterion that the DNB ratio should be no less than 2.0 along any cooling coil. The staff concludes that this is acceptable because there is adequate margin available to avoid DNB in the worse-case scenario of a power transient in the neutron multiplier.

With respect to the PCLS cooling surface of target solution, the NRC staff understands that the target solution is the heat source, which is essentially water in liquid phase at near atmospheric pressure, the PCLS coolant is water in liquid phase at a higher pressure than the target solution, and both target solution and coolant are at temperatures less than the boiling point. Under such a condition, the PCLS cooling surface is not expected to experience a heat flux higher than the critical heat flux of water at that condition or expected to cause coolant flow instability. Hence, the staff concludes that the occurrence of DNB along any PCLS cooling surface is not plausible.

Calculational Results – Passive Decay Heat Removal and Safe Shutdown

The target solution temperature and pressure limits ensure that the target solution does not undergo boiling. Pressure of the target solution is controlled by the TOGS. Gas pressure in the TSV headspace is regulated to -2 psig to 0 psig. Should a TOGS pressure control malfunction occur, a minimum pressure of 10.2 pounds per square inch absolute (psia) is maintained within the primary system boundary (PSB) by vacuum relief valves on the TSV. After shutdown or when the PCLS is inoperable, the target solution is transferred into the TSV dump tank and decay heat is passively removed by natural convection by the LWPS water surrounding the dump tank.

The TSV dump tank passive decay heat removal to the LWPS was calculated using the following conservative assumptions:

- The PCLS is not available.
- The TSV fission power prior to shutdown was 137.5 kW (licensed power limit is 125 kW).
- The bulk target solution temperature during irradiation (prior to shutdown) is less than 176°F (80°C).

- Natural convection from the outer surface of the dump tank to the LWPS water was assumed to be from a horizontal flat plate with heated surface facing downward.

- Horizontal heated tube internal natural convection from the inner surface of the dump tank to the LWPS water was assumed for the TSV dump tank inner shell and the LWPS.

- Permutations of tolerances were evaluated to ensure conservative results.

- The LWPS is maintained at a minimum water level below finished floor for the duration of the analysis.

- The target solution is assumed to remain in the TSV for up to 3 minutes prior to dump valve opening.

- The opening time of the dump valve is not more than 30 seconds.

- The drain time of the TSV is calculated assuming only one dump valve (out of two) opens.

Natural convection from the outer surface of the dump tank to the LWPS water was assumed to be from a horizontal flat plate with heated surface facing downward instead of a horizontal cylinder. This will result in a conservative estimate of the local convection coefficient at the bottom of the TSV dump tank where heat transfer is expected to be the worst. Using a horizontal cylinder would be less conservative because the sides of the cylindrical tank cool more readily than the underside of the tank. The sides of the tank resemble a vertical or inclined plate, which provides no restriction to convection currents, hence greater heat transfer would be expected.

The NRC staff verified that the modeling of heat transfer from the TSV dump tank inner shell to the LWPS water was appropriately conducted and relied on correlations that have been compared to test data to demonstrate their validity, and that the modeling of heat transfer within the target solution was based on conservative assumptions.

The NRC staff concluded that the adequate conservatism assumed in the calculational methodology for passive decay heat removal results in a bounding peak temperature of the target solution inside the TSV dump tank during shutdown. The large thermal mass provided by the LWPS provides adequate decay heat removal capability to provide cooling for the target solution. Figure 4a2.7-4 of the SHINE FSAR shows that the peak target solution temperature reaches approximately 194°F (90°C) after approximately 22 minutes (1318 seconds) and then decreases. The staff, therefore, concludes that the target solution remains below operating limits and that no boiling is expected to occur in the TSV dump tank during shutdown.

By assuming that active cooling was lost during shutdown and by conservatively neglecting all other heat transfer paths, the LWPS water temperature rise was also conservatively calculated. The heat rejected by the target solution from inside the TSV dump tank to the LWPS, the specific heat capacity of the LWPS water, and the mass of the LWPS water were used to calculate the water temperature rise. Safe shutdown with the target solution in the TSV dump tank can be achieved by less pool water than required for normal operation. The calculation assumed a pool depth as the minimum water level required to ensure safe shutdown. The

temperature rise in the LWPS is predicted after a decay heat period as shown in SHINE FSAR figure 4a2.4-1, “Light Water Pool Loss of Cooling Heatup Curve,” assuming that the pool is at the minimum allowable level and that there is no cooling to the pool. The water temperature of the LWPS remains below 140°F (60°C). A nominal pool water level would result in a temperature rise in the LWPS of less than 13°F (7°C) after a decay heat period.

The NRC staff reviewed the SHINE calculational methodology for the thermal-hydraulic analysis. The following SHINE documents were reviewed by the staff:

- “Target Solution Vessel Cooling,” SHINE CALC-2017-0006
- “Light Water Pool Temperature,” SHINE CALC-2018-0036
- “Target Solution Vessel (TSV) Dump Tank Thermal Hydraulics,” SHINE CALC-2018-0037
- “Target Solution Vessel (TSV) Thermal Hydraulics,” SHINE CALC-2018-0046

In addition, the NRC staff reviewed the applicability of the heat transfer correlations used in the calculations. The staff’s review of the documents verified that a correlation-based analytical methodology was employed for the safety-related calculations using limiting core conditions and conservative assumptions to obtain bounding results. Thermal-hydraulic correlations used in the analyses were derived from published peer reviewed literature, with the exception of the correlation for the heat transfer mechanism inside the TSV as described in the “TSV Tests” section of this SER. The staff’s review of the documents verified that the correlations employed were applicable to the SHINE facility and that the parameters of the SHINE facility are within the range of the parameters for which the correlations are valid. The staff concludes that the calculated results are acceptable and include adequate safety margin and that, therefore, adequate cooling capacity exists by the PCLS and the LWPS to prevent target solution overheating and loss of PSB integrity for anticipated system operating conditions.

Cooling System Design Bases

The SHINE facility does not have an active emergency cooling system for the TSV because the LWPS provides adequate passive heat removal capabilities, as discussed above. There is no forced cooling system in the LWPS. Heat is primarily removed from the LWPS by the PCLS through components submerged in the pool that are cooled by the PCLS.

The loss of the PCLS results in an IU Cell Safety Actuation on low PCLS flow or high PCLS temperature, depending on the cause of the reduction in cooling. The decreased cooling results in increased bulk temperatures in the TSV prior to target solution transfer to the TSV dump tank. The temperature of the target solution is expected to remain below 194°F (90°C).

The operational limits to prevent bulk boiling in the TSV are:

- TSV fission power less than 137.5 kW during normal operation (licensed power limit is 125 kW).
- PCLS cooling water minimum flow rate.

- PCLS cooling water temperature entering the SASS lower plenum of less than 77°F (25°C).

- PSB minimum pressure of 10.2 psia.

- Target solution uranium concentration to ensure that the power density of the limiting core condition is bounding.

The TSV fission power, PCLS cooling water flow rate, and PCLS cooling water temperature are protected by the TRPS. The PSB minimum pressure is protected by vacuum relief valves in the TOGS. The target solution uranium concentration is prepared and measured to ensure it is within 1 percent of the desired concentration.

Temperature monitoring of the target solution is provided for by indications to the operators. Temperature elements are located within thermowells contained within the TSV. Measurements are provided at multiple heights to compare TSV temperature profiles to expected profiles.

5a.4.2.5 Thermal-Hydraulic Design Conclusion

The SHINE FSAR describes and discusses all systems that remove and dispose of the heat from the target solution. Based on the above, the NRC staff concludes that adequate cooling capacity exists by the PCLS and the LWPS to prevent DNB in the cooling surfaces, and that the design does not allow overheating of target solution causing loss of PSB integrity for anticipated system operating conditions and during shutdown. The staff further concludes that the thermal-hydraulic methodology and the assumptions used are sufficiently conservative such that the calculated results include adequate safety margin and, therefore, are acceptable.

In addition, the NRC staff concludes that shutdown decay heat is satisfactorily removed from the target solution by the LWPS in a passive manner, including during long-term cooling and, therefore, the design provides reasonable assurance that the subcritical assembly achieves a safe shutdown condition from any operating condition.

5a.4.2.6 Primary Closed Loop Cooling System

The PCLS provides forced convection water cooling to the TSV and neutron multiplier during irradiation of the target solution and immediately prior to transferring the target solution from the TSV to the TSV dump tank. The PCLS also provides cooling of the LWPS by natural convection heat transfer to the PCLS components submerged in the pool. Each PCLS includes two pumps, a heat exchanger, and a cooling water cleanup system located in the primary cooling rooms.

The PCLS is designed to remove 170 kW of heat from the TSV and neutron multiplier in a single IU during full-power operation and during shutdown conditions when target solution is in the TSV. The PCLS is designed to maintain the pressure of the cooling water in the SASS higher than the internal pressure of the TSV. The major components are constructed of austenitic stainless steel.

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 system flowrate, is expected to provide 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

NRC staff's evaluation of the thermal-hydraulic calculations for the PCLS is provided in section 5a.4.2.4 of this SER.

The LWPS and the TSV are located within the primary confinement, which also provides confinement of the components of the PCLS located within the IU cell. The PCLS piping penetrations through the primary confinement are located above the minimum required water level in the pool.

Low cooling water flow causes an IU Cell Safety Actuation, which opens the TSV dump valves and allows the target solution to drain to the TSV dump tank. The dump valves are located in redundant flow paths and fail to a safe (open) position. The TSV dump valves are automatically opened by TRPS disconnecting power to the valves, resulting in a dump of the target solution 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 LWPS prevents the solution from boiling by natural convection heat transfer from the target solution to the surrounding water in the LWPS.

To prevent the drainage of primary cooling water from the subcritical assembly system (SCAS), the SCAS is located below grade in the LWPS. Portions of the PCLS located outside of the LWPS are above grade to prevent gravity drainage of the SCAS cooling channels.

Pressure, flow, temperature, conductivity, and level instrumentation monitor the operating parameters of the PCLS. 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 LWPS. 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. Sampling and analysis of the water from the PCLS is performed to ensure that the water quality requirements are being maintained and that contaminants are not present in the cooling water. The system operational controls are in the control room.

5a.4.2.7 Primary Closed Loop Cooling System Conclusion

The purpose of the PCLS is to remove heat from the core, where the core consists of that region of the TSV occupied by the target solution containing the fission power producing fissile material. Based on the above, the NRC staff concludes that the PCLS satisfies the principal purpose of the cooling system, which is to safely remove the fission and decay heat from the target solution and dissipate it to the environment, and that the analyses show that the components and the functional design of the PCLS will ensure that no limiting safety system settings (LSSS) will be exceeded through the normal range of operation. The staff, therefore, finds that the SHINE facility PCLS is acceptable for the issuance of an operating license.

5a.4.3 Secondary Cooling System

The NRC staff evaluated the sufficiency of the final design of SHINE's secondary cooling system, which consists of the RPCS and the PCHS, as presented in SHINE FSAR section 5a2.3 and 5a2.4, "Process Chilled Water System," in part, by reviewing the design

basis, process functions, components and interfaces, cooling functions and operation, cooling control, loss of cooling, component functions and locations, instrumentation and control, and other uses of the RPCS and the PCHS using the guidance and acceptance criteria from section 5.3, “Secondary Coolant System,” of NUREG-1537, Parts 1 and 2, and section 5a2.3, “Secondary Cooling System,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

5a.4.3.1 Radioisotope Process Facility Cooling System

The RPCS removes heat generated from within the RCA and rejects the heat to the PCHS. The RPCS is an intermediate closed loop forced liquid cooling system that recirculates cooling water. The RPCS removes heat from the PCLS. The RPCS is not a safety-related system and is not credited with preventing or mitigating any design basis events. 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 not available due to a loss of the RPCS, irradiation of the target solution is suspended and any target solution in the TSV is transferred from the TSV to the TVS dump tank and is passively cooled by the LWPS water.

SHINE FSAR section 5a2.3.2, “RPCS Analyses,” states that the RPCS is maintained at a higher pressure than the systems it serves. As such, 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. In addition, 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. The RPCS is a closed loop system located inside the RCA.

5a.4.3.2 Radioisotope Process Facility Cooling System Conclusion

The RPCS is an intermediate closed loop forced liquid cooling system that recirculates cooling water and removes heat from the PCLS. It is maintained at a higher pressure than the systems from which it removes heat to avoid potential leakage of radioactive contaminants into the RPCS. Based on the evaluation of the RPCS, the NRC staff concludes that, consistent with acceptance criteria in section 5a2.3 of the ISG augmenting NUREG-1537, Part 2, the SHINE facility is designed to ensure that the secondary cooling system (i.e., the RPCS) pressure is maintained at higher than the primary cooling system (i.e., the PCLS) pressure across the heat exchangers under all anticipated conditions, and that the secondary cooling system is closed. Therefore, the staff finds that the final design of the RPCS acceptable for the issuance of an operating license.

5a.4.3.3 Process Chilled Water System

SHINE FSAR section 5a2.4 describes the PCHS. The following design criterion from section 3.1 of the SHINE FSAR applies to this system:

> Criterion 26 - Cooling water: The radioisotope process facility cooling system and process chilled water system are provided to transfer heat from safety-related SSCs [structures, systems, and components] to the environment, which serves as the ultimate heat sink.

The PCHS is a closed loop chilled water system that rejects heat to the atmosphere by use of air-cooled chillers. The PCHS removes heat from the RPCS and rejects its heat to the environment. The RPCS is an intermediate closed loop cooling water system that removes heat

from the PCLS under normal operating conditions. The overall cooling system is a cascading design where the PCLS rejects heat to the RPCS, which rejects heat to the PCHS, which rejects heat to the environment.

The PCHS is comprised of circulation pumps, flow control valves, an expansion tank, a buffer tank, a glycol makeup unit, instrumentation, and packaged air-cooled chillers. These PCHS components are located outside the RCA and the primary confinement boundary. The PCHS interfaces with the RPCS at the supply and return connections of the RPCS heat exchanger.

The PCHS system is classified as a non-safety system because it is not credited with preventing or mitigating any design-basis events. During normal operating conditions, the non-safety PCHS and the non-safety RPCS transfer heat from safety-related SSCs to the environment, which serves as the ultimate heat sink. There is no direct PCHS interface with PCLS primary cooling, and PCHS component malfunctions will not lead to damage or to an uncontrolled release of radioactivity to the environment.

Although not credited for preventing or mitigating any-basis events, the PCHS is discussed in SHINE FSAR Chapter 13, “Accident Analysis,” because failure of the non-safety PCHS could adversely impact the RPCS cooling function supporting the safety-related PCLS. As described in SHINE FSAR section 13a2.1.3, “Reduction in Cooling,” PCLS, RPCS, and PCHS cooling pumps are driven by offsite power. Loss of coolant flow occurs due to power failure which could occur due to failure of a pump, inadvertent valve closure, or a pipe break. Loss of normal power results in loss of PCHS, loss of coolant flow in the PCLS cooling loop, and loss of neutron driver function and, therefore, the irradiation process is stopped. Loss of PCLS function is detected by low flow or high temperature signals that terminate the irradiation process upon loss of PCLS cooling. If active cooling to the TSV and neutron multiplier is unavailable due to a loss of the PCLS, irradiation of the target solution is suspended and any target solution in the TSV is transferred from the TSV to the TSV dump tank, which is passively cooled by the LWPS. Since required cooling during an accident is not dependent on PCHS function, the PCHS is not credited with preventing or mitigating any design basis events.

To protect against leakage and the remote possibility of radioactive material moving beyond the RPCS, the PCHS is maintained at a higher pressure than the RPCS so that any system leakage will tend to leak into the RPCS.

To address flooding concerns within the facility, berms and ramps are used to prevent a release of water from the RCA due to the postulated failure of the RPCS room, PCHS, or the facility demineralized water system. SHINE FSAR section 3.3.1.1.2, “Flood Protection from Internal Sources,” specifies that the resulting flooded water depth in the RCA from fire protection discharge does not result in adverse safety consequences and bounds the total water available in the PCHS and the RPCS cooling systems. Therefore, the design of the PCHS is acceptable with respect to protection against adverse effects from internal flooding.

5a.4.3.4 Process Chilled Water System Conclusion

The purpose of the PCHS is to removes heat from the RPCS and reject this heat to the environment. The PCHS is classified as a not safety-related and closed-loop system, not credited with preventing or mitigating any design basis events, and independent of any radiological process. In compliance with SHINE Design Criterion 26, the non-safety PCHS and the non-safety RPCS transfer heat from safety-related SSCs to the environment under normal operating conditions. Therefore, the NRC staff finds that the final design of the PCHS of the

SHINE secondary cooling system, as described in SHINE FSAR section 5a2.4, is acceptable for the issuance of an operating license.

5a.4.4 Primary Coolant Cleanup

The NRC staff evaluated the sufficiency of the final design of SHINE's primary coolant cleanup system, as presented in SHINE FSAR section 5a2.5, "Primary Closed Loop Cooling System Cleanup Side Stream," in part, by reviewing the design basis, process functions, process flow, system specifications, cleanup loop control and instrumentation, cleanup loop components, and maintenance and coolant testing of the primary coolant cleanup system using the guidance and acceptance criteria from section 5.4, "Primary Coolant Cleanup System," of NUREG-1537, Parts 1 and 2, and section 5a2.4, "Primary Coolant Cleanup System," of the ISG augmenting NUREG-1537, Parts 1 and 2.

Primary cooling for the TSV and related components is provided by the PCLS. A total of eight independent instances of PCLS are installed at the SHINE facility, one for each IU. Each PCLS contains a cleanup side stream. The primary closed loop cooling system cleanup side stream is connected to PCLS piping 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 maintains the required water quality limits of the PCLS. These quality limits are defined in SHINE FSAR table 5a2.2-1, "PCLS Operating Parameters."

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

- 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 is reasonably achievable (ALARA) goals.

The PCLS cleanup side stream is an integral part (or side stream) of the PCLS and is not an independent system. The safety functions of the PCLS are addressed in section 5a.4.2.6 of this SER. The cleanup components are located on a side stream through which the PCLS diverts a portion of the cooling water flow. The system cleanup side stream connects with PCLS piping at the outlet of the PCLS heat exchanger and returns inventory back into the PCLS piping downstream of the PCLS flow control valves prior to entering the primary confinement. The system removes contaminates that could become activated and radioactive materials from the PCLS cooling water. The 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.

As set forth in 10 CFR Part 20, facilities require a means for controlling and limiting radioactive effluents and radiation exposures within the regulatory limits. As an integral part of the PCLS, the location, shielding, and radiation monitoring of the water cleanup system are consistent with that of the PCLS. The PCLS cleanup side stream components are located outside the primary confinement and 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 area provides barrier and radiation monitoring to protect SHINE facility personnel,

members of the public, and various components and equipment of the SHINE facility by reducing radiation exposure.

SHINE FSAR section 11.2.2.2.9, “Primary Closed Loop Cooling System,” provides discussion of radioactive concerns with the PCLS. The PCLS has the potential for radioactive contamination due to minor leakage from the primary systems and activation products. Contamination would collect on the PCLS cleanup side-stream filters and deionizer resins. PCLS filters could become contaminated with radionuclides due to activation of corrosion particles as the water passes through the TSV, however, corrosion of the stainless-steel components within the PCLS is expected to be minimal. PCLS deionizer resins are contained in disposable deionizer units. The tanks are designed for complete replacement without removal of the ion exchange resins in the tanks. The disposable tanks are Class A waste. Spent filters and deionizer units are disposed of as radioactive waste via the solid radioactive waste processing system.

The 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.

5a.4.4.1 Primary Coolant Cleanup Conclusion

Based on its review, the NRC staff finds that the level of detail provided on the PCLS cleanup side stream system demonstrates an adequate description for the final design because (1) the application sufficiently defines system operation in accordance with 10 CFR 50.34(b)(2) and (2) the system has been designed in accordance with the requirements of 10 CFR Part 20 and with regard to the ALARA program guidelines. Therefore, the final design of the system is acceptable for the issuance of an operating license.

5a.4.5 Primary Coolant Makeup Water System

The NRC staff evaluated the sufficiency of the final design of SHINE’s primary coolant makeup water system, as presented in SHINE FSAR section 5a2.6, “Facility Demineralized Water System,” in part, by reviewing the design basis, process functions, process flow, design specifications, control and instrumentation, and components of the primary coolant makeup water system using the guidance and acceptance criteria from section 5.5, “Primary Coolant Makeup Water System,” of NUREG-1537, Parts 1 and 2, and section 5a2.5, “Primary Coolant Makeup Water System,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The FDWS provides makeup water to the PCLS, RPCS, FCHS, MEPS hot water loop subsystem, light water pool, and 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 and the facility chemical reagent system (FCRS) are supplied demineralized water from the FDWS.

The FDWS is not safety related and not credited with preventing or mitigating any design-basis events. The FDWS consists of a reverse osmosis (RO) skid located outside of the RCA. On loss of normal power, the FDWS pumps will not be operational, which is acceptable because the FDWS is not relied on to provide water inventory in the loss of normal power condition.

The main function of the non-safety FDWS is to provide makeup of cooling water loss in the PCLS and light water pool that 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. The FDWS supplies RO and deionized water for plant systems requiring RO-processed water, and through deionizers to other systems requiring deionized water. The FDWS deionizer units house deionization resins for the removal of contaminants and the reduction of water conductivity.

The FDWS consists of two recirculation loops (i.e., one inside the RCA and one outside the RCA) with an RO storage tank and two 100-percent capacity pumps for each recirculation loop. A portion of the RO water is supplied to systems outside the RCA with the balance supplied to the RO storage tank located inside the RCA. Redundant pumps circulate water from the respective RO storage tank to various systems within each loop. Each loop requires one of the two pumps to support normal operation. Recirculated water is supplied directly to systems requiring RO-processed water or processed through deionizers to meet the system criteria.

The FDWS RO loop outside the RCA is supplied water from the facility potable water system (FPWS) and stored in a tank located outside the RCA to maintain adequate system supply volume. The RO loop and tank outside the RCA are located downstream of a backflow prevention device that acts as the system boundary between the FPWS and the FDWS. The RO loop outside the RCA provides inventory to a second tank located inside the RCA. A second backflow prevention device is provided at the boundary where the FDWS enters the RCA. For additional protection, backflow prevention devices are also installed at the system boundaries of the systems served by the FDWS. The PCLS, RPCS, LWPS, and MEPS piping includes backflow prevention components at the interface with the FDWS, which prevents potentially contaminated cooling water from coming into contact with the makeup water.

Flow from the RO loop is controlled by level instrumentation in the RO storage tank. Tank level is provided with high- and low-level alarms. As indicated in SHINE FSAR table 5a2.6-2, “FDWS Components,” instrumentation is provided for FDWS operating parameters (pressure, temperature, conductivity, flow, and level). Sampling and trending of the system is performed to detect malfunctions in the deionizer units and the RO skid.

To address flooding concerns within the facility, berms and ramps are used to prevent a release of water from the RCA due to the postulated failure of the RPCS room, the PCHS, or the FDWS.

5a.4.5.1 Primary Coolant Makeup Water System Conclusion

The FDWS includes all components and piping associated with the system from the potable water source to the points of discharge to other systems. The system is classified as not safety-related, is not credited with preventing or mitigating any design-basis events, and is isolated from any radiological process. Therefore, the NRC staff finds that the final design of the FDWS, as described in SHINE FSAR section 5a2.5, is acceptable for the issuance of an operating license.

5a.4.6 Nitrogen-16 Control

The NRC staff evaluated the sufficiency of the final design of SHINE's N-16 control, as presented in SHINE FSAR section 5a2.7, "Nitrogen-16 Control," using the guidance and acceptance criteria from section 5a2.6, "Nitrogen-16 Control System," of the ISG augmenting NUREG-1537, Parts 1 and 2.

SHINE FSAR section 5a2.7 describes the methods to control N-16, which is generated in the PCLS and the light water pool by neutron activation of oxygen. The SHINE FSAR describes the function of a delay tank to allow for radioactive decay of N-16 prior to exiting the shielded area. It also describes the use of an air separator to remove entrained gases, which includes N-16, from the PCLS water and to direct the N-16 into the headspace of the PCLS expansion tank as shown in SHINE FSAR figure 5a2.2-1, "Primary Closed Loop Cooling System Flow Diagram." The PCLS headspace is vented to the radiological ventilation zone 1 exhaust.

5a.4.6.1 Nitrogen-16 Control Conclusion

The NRC staff reviewed the description of the N-16 control method in the SHINE FSAR and finds that the final design of the delay tank and the venting of the PCLS expansion tank provides additional time for the decay of the relatively short-lived N-16 (7.1 seconds), which, along with the applicant's radiation protection program and ALARA program discussed in Chapter 11 of this SER, are effective to help limit personnel exposures from N-16 to below the radiation exposure limits in 10 CFR Part 20. Therefore, the staff concludes that there is reasonable assurance that the facility will function in such a way as to maintain radiation exposure from N-16 below the limits in 10 CFR Part 20 to facility staff and the public and as such the final design of the system is acceptable for the issuance of an operating license.

5a.4.7 Auxiliary Systems Using Primary Coolant

The NRC staff evaluated the sufficiency of the final design of SHINE's auxiliary systems using primary coolant, as presented in SHINE FSAR section 5a2.8, "Auxiliary Systems Using Primary Coolant," using the guidance and acceptance criteria from section 5a2.7, "Auxiliary Systems Using Primary Coolant," of the ISG augmenting NUREG-1537, Parts 1 and 2.

SHINE FSAR section 5a2.8 states that the SHINE facility auxiliary systems do not utilize the PCLS for cooling. The NRC staff reviewed SHINE FSAR figure 5a2.2-1 and the PCLS design bases and functional requirements, as described in SHINE FSAR section 5a2.2.1, "Design Bases and Functional Requirements," and finds that the PCLS directly cools the TSV and neutron multiplier. Additionally, the staff finds that the PCLS does not provide any additional direct cooling functions for any auxiliary systems in the SHINE facility.

5a.4.7.1 Auxiliary Systems Using Primary Coolant Conclusion

Since the PCLS does not cool any auxiliary systems in the SHINE facility, the NRC staff concludes that the PCLS functional cooling requirements to remove the heat from the TSV and neutron multiplier are not impacted and, therefore, are acceptable for the issuance of an operating license.

5a.4.8 Proposed Technical Specifications

In accordance with 10 CFR 50.36(a)(1), the NRC staff evaluated the sufficiency of the applicant’s proposed technical specifications (TSs) for the SHINE cooling systems as described in SHINE FSAR Chapter 5.

The proposed TS 2.2, “Limiting Safety System Settings (LSSS),” Table 2.2, “Limiting Safety System Settings,” states, in part, the following:

LSSS	Variable	Setpoint	Applicability
LSSS 2.2.7	Low PCLS flow	**[[Proprietary]]**; IU Cell Safety Actuation delayed by ≤ 180 seconds	Modes 1 and 2
LSSS 2.2.8	High PCLS temperature	≤ 72.9°F; IU Cell Safety Actuation delayed by ≤ 180 seconds	Modes 1 and 2

The LSSS 2.2.7 and LSSS 2.2.8 setpoints prevent overheating of the target solution, which could lead to boiling and pressurization of the TSV and could subsequently challenge the PSB pressure safety limit. Thermal-hydraulic analysis used to obtain the values of the setpoints was based on assuming the lowest allowable PCLS flow rate and the maximum PCLS cooling water temperature of 77°F (25°C), as described in section 4a2.7, “Thermal Hydraulic Design,” of the SHINE FSAR. The NRC staff evaluation is provided in section 5a.4.2.1 of this SER. The staff finds that the LSSS 2.2.7 and LSSS 2.2.8 setpoint values are bounded by the calculated low PCLS flow and high PCLS temperature values. The LSSSs are protected by the TRPS IU Cell Safety Actuation setpoints. The time delay prior to an IU Cell Safety Actuation is based on the acceptability of a complete loss of cooling without neutron driver operation for up to 3 minutes (180 seconds) prior to transferring target solution to the TSV dump tank. Because the proposed low PCLS flow and high PCLS temperature setpoints and the safety actuation time delay are based on the analytical limits calculated using thermal-hydraulic analysis assuming the lowest allowable PCLS flow rate and the highest PCLS temperature, the staff finds LSSS 2.2.7 and LSSS 2.2.8 acceptable.

The proposed TS 4.2, “Coolant Systems,” Design Feature (DF) 4.2.1 states the following:

DF 4.2.1	1. Each subcritical assembly system is submerged in an individual light water pool. 2. Each light water pool is provided a seismically qualified stainless steel liner. 3. Piping penetrations into the stainless steel liner are located above the minimum acceptable light water pool water level for decay heat removal, or a specific evaluation is performed to determine the potential for loss of pool water through the penetration. Piping penetrations into the light water pool with the potential for siphoning below the minimum acceptable water level contain anti-siphon devices or other means to prevent inadvertent loss of pool water. 4. Each light water pool is designed to maintain temperatures ≥ 50°F and ≤ 95°F.

The design features of the light water pool include that a subcritical assembly is submerged in the pool, which provides cooling to the TSV and TSV dump tank as described in section 4a2.4.2, “Light Water Pool,” of the SHINE FSAR. The design features of the pool were the basis for the thermal-hydraulic calculations demonstrating that adequate cooling is provided to the TSV and TSV dump tank during all anticipated operating and shutdown conditions, as discussed in section 5a.4.2.1 of this SER and, therefore, are acceptable. Furthermore, each light water pool is designed with a seismically qualified stainless-steel liner, which provides reasonable assurance that adequate cooling water is provided during normal operation, as well as during a design basis earthquake and design-basis accident events. Therefore, the NRC staff finds DF 4.2.1 acceptable.

5a.5 Review Findings

As described in SHINE FSAR sections 5a2.3 and 5b, the RPCS serves as a secondary cooling system for the IUs and provides cooling to the RPF. The review findings provided below apply to both the IF and RPF.

The NRC staff reviewed the descriptions and discussions of SHINE’s cooling systems, as described in SHINE FSAR sections 5a2 and 5b, as supplemented, against the applicable regulatory requirements and using appropriate regulatory guidance and acceptance criteria.

Based on its review of the information in the SHINE FSAR and independent confirmatory review, as appropriate, the NRC staff determined that:

(1) SHINE described the facility cooling systems and identified the major features or components incorporated therein for the protection of the health and safety of the public.

(2) The processes to be performed, the operating procedures, the facility and equipment, the use of the facility, and other TSs provide reasonable assurance that the applicant will comply with the applicable regulations in 10 CFR Part 50 and 10 CFR Part 20 and that the health and safety of the public will be protected.

(3) The issuance of an operating license for the facility would not be inimical to the common defense and security or to the health and safety of the public.

Based on the above determinations, the NRC staff finds that the descriptions and discussions of SHINE's cooling systems are sufficient and meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

5b Radioisotope Production Facility Cooling Systems

SER section 5b, "Radioisotope Production Facility Cooling Systems," provides an evaluation of the final design of SHINE's RPF cooling systems, as presented in SHINE FSAR section 5b, "Radioisotope Production Facility Cooling Systems."

5b.1 Areas of Review

SHINE FSAR section 5a2.3 describes the RPCS, which serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF. Therefore, the areas of review related to the RPCS presented in section 5a.1, "Areas of Review," of this SER are applicable to both the SHINE IF and RPF.

5b.2 Summary of Application

As stated above and described in SHINE FSAR sections 5a2.3 and 5b, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF. Therefore, the summary provided in section 5a.2, "Summary of Application," of this SER applies to both the SHINE IF and RPF.

5b.3 Regulatory Requirements and Guidance and Acceptance Criteria

As described in SHINE FSAR section 5a2.3, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF. Therefore, the regulatory requirements and guidance and acceptance criteria provided in section 5a.3, "Regulatory Requirements and Guidance and Acceptance Criteria," of this SER apply to both the SHINE IF and RPF.

5b.4 Review Procedures, Technical Evaluation, and Evaluation Findings

As described in SHINE FSAR section 5a2.3, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF; therefore, the review procedures, technical evaluation, and evaluation findings provided in section 5a.4, "Review Procedures, Technical Evaluation, and Evaluation Findings," of this SER apply to both the SHINE IF and RPF.

5b.5 Review Findings

As described in SHINE FSAR section 5a2.3, the RPCS serves as a secondary cooling system for the IUs in the IF and provides cooling to the RPF; therefore, the review findings provided in section 5a.5, "Review Findings," of this SER apply to both the SHINE IF and RPF.