4.0 IRRADIATION UNITS AND RADIOISOTOPE PRODUCTION FACILITY DESCRIPTION

The facility description addresses the principal features, operating characteristics, and parameters of the SHINE Medical Technologies, LLC (SHINE, the applicant) facility irradiation units (IUs) (which constitute the irradiation facility (IF)) and radioisotope production facility (RPF). An IU is an accelerator-driven subcritical operating assembly that operates with a significant subcritical neutron multiplication factor (M) and is used for the irradiation of an aqueous uranyl sulfate target solution, resulting in the production of molybdenum-99 (Mo-99) and other fission products. The primary function of the RPF is to extract, purify, package, and ship radioisotopes, including Mo-99.

This chapter of the SHINE operating license application safety evaluation report (SER) describes the review and evaluation by the U.S. Nuclear Regulatory Commission (NRC, the Commission) staff of the final design of the SHINE IUs and RPF as presented in chapter 4, “Irradiation Unit and Radioisotope Production Facility Description,” of the SHINE final safety analysis report (FSAR) and supplemented by the applicant’s responses to staff requests for additional information (RAIs).

4a Irradiation Facility Description

SER section 4a, “Irradiation Facility Description,” provides an evaluation of the final design of SHINE’s IUs as presented in SHINE FSAR section 4a2, “Irradiation Facility Description.”

The facility description addresses the principal features, operating characteristics, and parameters of the IF. The primary function of the IUs and, consequently, the IF is to irradiate the target solution to produce Mo-99.

4a.1 Areas of Review

The NRC staff reviewed SHINE FSAR section 4a2 against applicable regulatory requirements, using appropriate regulatory guidance and acceptance criteria, to assess the sufficiency of the final design and performance of the SHINE IUs. As part of this review, the staff evaluated descriptions and discussions of the SHINE IF, with special attention to principal safety considerations that were factored into the design and operation of the IUs and the IF. The final design bases of the SHINE IUs and IF were evaluated to ensure that the design bases and functions of the structures, systems, and components (SSCs) are presented in sufficient detail to allow a clear understanding of the facility and to ensure that the facility can be operated for its intended purpose and within regulatory limits for ensuring the health and safety of the workers and the public. Drawings and diagrams were evaluated to determine if they present a clear and general understanding of the physical facility features and of the processes involved.

Areas of review for this section include the subcritical assemblies, neutron driver assemblies, target solution vessel (TSV) and light water pool, the IF biological shield, nuclear design, thermal-hydraulic design, and gas management system.

4a.2 Summary of Application

The SHINE FSAR includes information that describes the facility, presents the design bases and the limits on its operation, and presents a safety analysis of the SSCs of the facility. The SHINE IF includes eight IUs and their supporting systems.

An IU is an accelerator-driven subcritical operating assembly used for the irradiation of an aqueous uranyl sulfate target solution, resulting in the production of Mo-99 and other fission products. The accelerator neutron source uses deuterium-tritium fusion reactions in the accelerator target chamber to produce high energy neutrons. The neutrons are multiplied in the natural uranium neutron multiplier and the uranyl sulphate target solution to significantly increase the number of neutrons produced in the TSV compared to the initial deuterium-tritium neutron source. The resultant fission reactions in the target solution create, among others, the fission product Mo-99.

4a.3 Regulatory Requirements and Guidance and Acceptance Criteria

The NRC staff reviewed SHINE FSAR chapter 4 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.

4a.3.1 Applicable Regulatory Requirements

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

- Title 10 of the *Code of Federal Regulations* (10 CFR) 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”

4a.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.

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

The NRC staff performed a review of the technical information presented in SHINE FSAR section 4a2, as supplemented, to assess the sufficiency of the final design and performance of the SHINE IF for the issuance of an operating license. The sufficiency of the final design and performance is determined by ensuring that they meet applicable regulatory requirements, guidance, and acceptance criteria, as discussed in section 4a.3, “Regulatory Requirements and Guidance and Acceptance Criteria,” of this SER. The findings of the staff review are described in section 4a.5, “Review Findings,” of this SER.

The SHINE IF consists of up to 8 IUs that irradiate a uranyl sulfate target solution with the goal of producing Mo-99. The target solution uses low-enriched uranium (LEU) with a target enrichment of 19.75 percent. The irradiation of the target solution is driven by a neutron source produced from deuterium-tritium fusion reactions. The deuterium-tritium fusion reactions are driven by an accelerator and the source neutrons pass through a natural uranium multiplier before entering the TSV, which holds target solution in which neutrons are further multiplied. The steady-state maximum fission power level of each IU is 125 kilowatts (kW). Each IU is cooled by a forced convection cooling system during normal operation. After the target solution is irradiated in the TSV in the IU, the solution is transferred to the RPF for the extraction from it of radioisotopes, including the fission product Mo-99.

4a.4.1 Summary Description

The NRC staff evaluated the sufficiency of the summary description of the IU, as presented in SHINE FSAR section 4a2.1, “Summary Description,” using the guidance and acceptance criteria from section 4a2.1, “Summary Description,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The application states that each IU consists of a light water pool which contains the subcritical assembly system (SCAS), the neutron driver assembly system (NDAS), the neutron flux detection system (NFDS), and the TSV dump tank. These are surrounded by a concrete biological shield. The systems supporting the IUs are the tritium purification system (TPS), the TSV off-gas system (TOGS), and the primary closed loop cooling system (PCLS). The atmosphere of the IUs and the TOGS is part of the Radiation Ventilation Zone 1 (RVZ1) exhaust subsystem (RVZ1e). Each IU has five modes of operation. These modes of operation are:

- Mode 0 Solution Removed: No target solution in the SCAS
- Mode 1 Startup: Filling the TSV using a 1/M startup methodology
- Mode 2 Irradiation: Activating the neutron driver and irradiating the target solution
- Mode 3 Post-Irradiation (Shutdown): Target solution is drained to the TSV dump tank
- Mode 4 Transfer to RPF: Target solution is transferred from the TSV dump tank to the RPF

The IU system is designed to be subcritical for all modes of operation. The modes of operation are described in detail in SHINE FSAR section 4a2.6.1 and the operational state of key components in the different modes is shown in proposed technical specification (TS) table 1.3, “IU Modes of Operation.”

SHINE IUs are similar in size and power to some research and test reactors, but they are subcritical and have features and systems that are different than those found in solid fuel reactors. Although subcritical, SHINE IUs have some features in common with a class of reactors called aqueous homogeneous reactors (AHRs) (Oak Ridge National Laboratory (ORNL), “Fluid Fuel Reactors, Part 1, Aqueous Homogeneous Reactors”). AHRs are critical systems, but they operate at power densities similar to those at which SHINE IUs will operate. Although there are currently no AHRs operating in the United States, there is previous AHR operating experience, including the use of uranyl sulfate as fuel. There has been significant interest in using AHRs for Mo-99 production (International Atomic Energy Agency (IAEA)-TECDOC-1601, “Homogeneous Aqueous Solution Nuclear Reactors for the Production of Mo-99 and Other Short Lived Radioisotopes”). There are several AHRs in operation outside of the United States that are mostly used for criticality studies. The one most similar to a SHINE IU is the ARGUS AHR (Los Alamos National Laboratory (LANL)-UR-18-29657, “The ARGUS Solution Reactor and Molybdenum Production: A Summary Report Based on Open Literature) at the Kurchatov Institute in Russia. The ARGUS AHR has been operating since 1981. It originally used high enriched uranium uranyl sulfate fuel but was converted to LEU uranyl sulfate fuel in 2014. It has a heat exchanger in the aqueous fuel and an off-gas handling system that has a recombiner and a condenser to return water back to the fuel solution, which is similar to the SHINE system.

Based on the information provided in SHINE FSAR section 4a2.1, the NRC staff finds that the summary description of the facility and processes of the SHINE IF meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4a.4.2 Subcritical Assembly

The primary components that make up the SCAS are the TSV, the TSV dump tank, and the neutron multiplier, which are both supported and positioned by the subcritical assembly support structure (SASS). The SCAS is submerged in a light water pool (SHINE FSAR section 4a2.4.2) and located directed beneath the NDAS (SHINE FSAR section 4a2.3). The SCAS and the NDAS are the primary components of the IU. The TSV contains the LEU uranyl sulfate target solution in a high source multiplication configuration.

4a.4.2.1 Target Solution

The NRC staff evaluated the sufficiency of the SHINE target solution, as presented in SHINE FSAR section 4a2.2.1, “Target Solution,” using the guidance and acceptance criteria from section 4a2.2.1, “Reactor Fuel,” of the ISG augmenting NUREG-1537, Parts 1 and 2. The staff notes that, while the target solution is not considered reactor fuel, it is similar in nature and behavior to the liquid fuel loading of an AHR and, therefore, the guidance in the ISG augmenting NUREG-1537 can appropriately be applied to its review.

The applicant stated that the SHINE target solution is a uranyl sulfate solution with an enrichment of 19.75 +/- 0.2 percent, which is also stated in proposed TS design feature (DF) 4.3.1. The uranium concentration has been estimated using SHINE’s neutronics models of the system. The convention for uranium concentration as specified in the SHINE FSAR is grams of uranium per liter of target solution. Fuel solution of this composition has been used in a number of different research programs, as cited in SHINE FSAR section 4a2.2.1.13. Based on these analyses, the chemical and physical characteristics of the target solution constituents are compatible with one another. Each irradiation cycle has a duration of 5.5 days, with some makeup solution expected to be added to counter process losses. SHINE FSAR section 4a2.6.2 states that no precipitation is anticipated and that maximum burn-up is expected to be a low fraction of the initial uranium concentration. The final SHINE target solution operating parameter range will be determined during startup testing. This will be guided by historical operating data from the operation of uranyl sulfate solution reactor systems. The maximum uranium concentration is specified in proposed TS limiting condition for operation (LCO) 3.8.2.

SHINE FSAR section 4a2.2.1.4 states that the primary system boundary (PSB) components were designed to be compatible with the target solution to avoid corrosion and other unwanted metallurgical effects that could compromise the PSB integrity.

SHINE FSAR section 4a2.2.1.6 states that mixing in the TSV takes place by natural convection. The highest heat generation will occur near the center of the solution, and the surfaces adjacent to cooling flow will be the coolest. Thus, there will be an upward flow through the center of the TSV and a downward flow near the cooled surfaces. Non-uniformities, such as non-uniform void distribution, non-uniform temperatures, and non-uniform power distribution, are not expected to impact operational limits.

SHINE FSAR section 4a2.8 states that off-gas formation is handled by the TOGS. Calculations indicate that plutonium and poison buildup, along with changes in pH, will not have a significant impact on the operation of the IUs. The target solution will also be processed through the molybdenum extraction and purification system (MEPS) after each irradiation cycle. After the extraction of the molybdenum, the target solution will be sent to a holding tank where measurements will determine whether the solution is within target parameters. If the solution's parameters are outside of the acceptable range, then it is adjusted to bring the parameters back within the acceptable range.

The ISG augmenting NUREG-1537, Part 2, section 4a2.2.1, "Reactor Fuel," Acceptance Criteria, states, in part, that the "design bases for the fuel should be clearly presented, and the design considerations and functional description should ensure that fuel conforms to the bases." The NRC staff finds that SHINE FSAR section 4a2.2 illustrates a high-level functional description of each of the components of the target solution system, along with the underlying design basis of each component such that the solution-barrier integrity is maintained. Additionally, all described DFs of the target solution system were supported with appropriate tables, figures, references, and experimental programs.

The ISG augmenting NUREG-1537, Part 2, section 4a2.2.1 states, in part, that a description of the fuel (and solvent) should be given with respect to its chemical and physical properties, along with the relationship of the fuel solution to the environment and fuel barrier It also states that the phenomena capable of changing the fuel operating composition and structural damage, along with the operating physical forces, should also be described with respect to the integrity of the fuel barrier. SHINE FSAR section 4a2.2.1 describes the physical and chemical characteristics of the target solution (chemistry, uranium loading and enrichment, and radiolytic gas formation) in each of its sub-sections, including the solution's relationship to the primary barrier. Additional details about the control of the uranium concentration, pH, and the catalyst with regards to precipitation of uranium peroxide was provided by letter dated July 30, 2020 (Agencywide Documents Access and Management System Accession No. ML20220A341). The NRC staff finds that the SHINE FSAR adequately describes the target solution composition components and addresses the pH of the solution and the bounds of pressure, temperature, uranium concentration, catalyst concentration, and power density that are being applied to the solution.

The ISG augmenting NUREG-1537, Part 2, section 4a2.2.1 also notes that the potential for fission product precipitation should be addressed. SHINE FSAR section 4a2.2.1.6 and table 4a2.2-1 describe the operating limits and catalysts in the target solution that were defined to prevent fission product precipitation at nominal conditions.

The ISG augmenting NUREG-1537, Part 2, section 4a2.2.1 also states that a description of radiolytic gas generation and the management of these gases should be given. This issue is described in SHINE FSAR section 4a2.2.1.5, which discusses radiolysis rates for uranyl sulfate systems during fission. By letter dated June 17, 2020 (ML20188A302), SHINE provided additional details about radiolysis gas formation and how it is calculated.

The SHINE FSAR addresses each of the nominal phenomena that are expected to impact the changes in target solution composition (burnup and radiolytic gas formation), including target solution makeup addition and fission product precipitation, along with the implications to reactivity control of the system due to these system changes. The applicant also described design information, operational details, setpoints, and means for accomplishing surveillances of the system, to form the basis for TSs.

The NRC staff performed an evaluation of the SHINE target solution relative to the acceptance criteria in the ISG augmenting NUREG-1537, Part 2. The staff found that the target solution design information is sufficiently supported in the SHINE FSAR with adequate functional descriptions, tables, text, and referenced reports. The design limits of the target solution are clearly described such that the safety related implications of these limits, and their relationship to the rest of the facility is also described. The presented design information is described at the level of detail such that it would form the basis for TSs and an operational means to monitor the facility and ensure its safe operation. The staff finds that the target solution design and its interface with the pressure boundary offers reasonable assurance that the health and safety of the public is protected during operation. Therefore, the staff concludes that the target solution design basis meets the applicable regulatory requirements and guidance for the issuance of an operating license.

4a.4.2.2 Reactivity Control Mechanisms

The NRC staff evaluated the sufficiency of the SHINE reactivity control mechanisms, as presented in SHINE FSAR section 4a2.2.2, “Reactivity Control Mechanisms,” using the guidance and acceptance criteria from section 4a2.2.2, “Control Rods,” of the ISG augmenting NUREG-1537, Parts 1 and 2. The staff notes that while the application does not propose to use control rods, the basis and underlying principles of the guidance in the ISG augmenting NUREG-1537 can still be applied to the SHINE reactivity control mechanisms.

The applicant stated that the IUs are not intended to achieve criticality during normal operation and so no control rods are included in the SHINE design. Reactivity is primarily determined by six variables: uranium concentration in the target solution, uranium enrichment, TSV fill volume, neutron driver source strength, target solution headspace pressure, and temperature of the PCLS. During operation, the last four variables can be manipulated to control reactivity, while the others are not significantly altered during operation. The systems used to monitor reactivity are described in detail in SHINE FSAR chapter 7.

SHINE FSAR section 4a2.2.2 states that the variables that influence reactivity are set by the design and are controlled during operation of the facility. Instrumentation is used to confirm that the neutron flux levels don’t exceed trip setpoints during Mode 1. The target solution uranium concentration, uranium enrichment, and TSV fill volume do not change significantly during irradiation (Mode 2). The target solution concentration is established during solution preparation. The vacuum lift tank transfer system is used to transfer the prepared target solution from the target solution hold tank to the TSV during the 1/M experiment fill procedure that establishes the TSV fill volume. The other variables that influence reactivity are controlled during irradiation. For the TOGS, the gas space pressure above the target solution operates at a value less than the pressure of the atmosphere outside the TOGS. The condensate return lines return water to the target solution to reduce uranium concentration changes due to off-gas formation. The design of the TOGS limits the maximum amount of water holdup in the TOGS. For the PCLS system, the temperature of the cooling water is monitored by the TSV reactivity protection system (TRPS) and the target solution is drained to the TSV dump tank if the PCLS temperature limits are exceeded. The reflector temperatures are kept stable by the large thermal mass of the light water pool.

When an abnormal condition arises that requires the IU to be shut down (e.g., loss of power, high flux, high hydrogen concentration), the control system of the neutron driver assembly will shut down the accelerator and terminate the reaction, and the target solution is drained into a criticality-safe geometry TSV dump tank.

Based on the information provided in the SHINE FSAR, the NRC staff finds that the means for reactivity control are adequately described in the FSAR and meet the applicable acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4a.4.2.3 Neutron Moderator and Reflector

The NRC staff evaluated the sufficiency of the solid neutron moderators and reflectors, as presented in SHINE FSAR section 4a2.2.3, “Neutron Moderator and Reflector,” using the guidance and acceptance criteria from section 4a2.2.3, “Solid Neutron Moderator and Neutron Reflector,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The applicant stated that the light water pool, which surrounds the TSV, provides neutron moderation and reflection. Additional information is presented in SHINE FSAR section 4a2.4.2. The neutron multiplier that serves to increase the neutron population in the TSV is described in SHINE FSAR section 4a2.2.6.

4a.4.2.4 Subcritical Multiplication Source

The NRC staff evaluated the sufficiency of the subcritical multiplication source, as presented in SHINE FSAR section 4a2.2.4, “Subcritical Multiplication Source,” using the guidance and acceptance criteria from Section 4a2.2.4, “Neutron Startup Source,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The SHINE subcritical multiplication source is a fixed neutron startup source that is used when the neutron driver is not operating. The startup source provides an adequate and stable population of background neutrons so that neutron multiplication in the subcritical assembly can be accurately and reliably measured while filling the TSV with target solution. Its output is several orders of magnitude less than the neutron driver and is suitable for performing 1/M measurements during Mode 1 startup operations. The subcritical neutron multiplication factor (M) relates the source neutron level to a steady-state neutron level and can be used to predict when criticality will occur. It is defined as 1/(1-k) where k is the multiplicative increase of the neutron population from one generation of neutrons to the next generation. A system is critical when k is equal to 1. When a system is critical, M goes to infinity and 1/M goes to zero.

The startup sources described in the SHINE FSAR, Americium-Beryllium or Plutonium-Beryllium with alpha-neutron reactions, are customarily used as startup sources in nuclear reactors. The physical and operating characteristics of the sources that are specified in this section are: the energy spectrum, the materials from which the sources are constructed, the orientation of the sources, the nuclear reaction and source strength, the radiation environment at which the sources operate, and the procedures used to verify the integrity of the sources prior to startup.

Based on the information provided in the SHINE FSAR, the NRC staff finds that the SHINE subcritical multiplication source is adequately described and meets the applicable acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4a.4.2.5 Subcritical Assembly Support Structures

The NRC staff evaluated the sufficiency of the SASS, as presented in SHINE FSAR section 4a2.2.5, “Subcritical Assembly Support Structure,” using the guidance and acceptance criteria from section 4a2.2.5, “Reactor Internals Support Structures,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The applicant stated that the SASS maintains the geometry of the target solution during irradiation. It contains the TSV and supports the TSV dump lines, TSV overflow lines, TOGS piping, and associated instrumentation. The SASS also functions to force coolant through cooling paths to cool the TSV and neutron multiplier. It acts as an additional fission product barrier in the event of a TSV failure. The PCLS is attached to the SASS and operates at a higher pressure than the TSV. This reduces or eliminates leakage of target solution to the SASS in the event of a breach of the PSB. The SASS has a design pressure of 100 pounds per square inch (psi).

The applicant stated that the SASS is designed to conservatively withstand all design basis loads, including thermal, seismic, and hydrodynamic loads imposed by the light water pool during a seismic event. It is also designed to withstand all thermal and hydraulic forces imposed by the coolant loop and target solution during normal and off-normal operating conditions.

The applicant stated that the 304L stainless steel used to construct the SASS was chosen due to its compatibility with the chemical environment and demonstrated performance under the expected neutron flux. The SASS has a 30-year design life. By letter dated January 28, 2022, in response to NRC staff RAIs, the applicant provided additional information about the neutron spectrum and corrosion testing relevant to the SASS and the TSV (ML22028A224). The applicant also stated that the SASS will be subject to a periodic inspection and surveillance program designed to monitor for corrosion and radiation damage. The neutron spectrum is largely thermalized at the location of the SASS structures and the design data used to assess radiation damage effects is applicable.

In its response to NRC staff RAI 4a-17, SHINE contended that stagnant flow areas are not expected in the area between the SASS inner baffle and the SASS inner wall because this channel is filled with cooling water from the PCLS and, while the PCLS does not force water through this channel, flow is provided via natural convection and radiolysis bubbles. The staff notes that this area between the cooling channel 3 (CC3) and SASS inner wall just above this ring is not expected to be well swept by fluid flow given its long, slender cavity and the lack of a significant thermal driving force in the area. The staff believes that it is possible that this location might have stagnant flow and be subject to off-normal coolant chemistry that could cause corrosion and possible cracking due to weld residual stresses. However, there are several mitigating factors that will decrease this likelihood. First, the relatively low temperature at this location is not normally conducive to promoting excessive corrosion or stress-corrosion cracking. Additionally, the PCLS system has a cleanup system to control water chemistry and remove particulates, which decreases the likelihood that significant off-normal water conditions will exist. Further, this ring and the associated connection between CC3 and the SASS inner wall appears to serve no structural purpose as it is only intended to channel flow into CC3. Therefore, even if significant cracking or other degradation were to occur in this region, the only significant potential consequence is that flow could bypass cooling channels. This situation could degrade the cooling of the TSV and cause an increase in the temperature of the target solution. However, the affected IU would shut down if the target solution temperature exceeds the maximum allowed value of 176 degrees Fahrenheit (°F) specified in proposed

TS LCO 3.1.4. Therefore, the staff finds that the design limits used by SHINE for radiation fluence to limit radiation damage are applicable, and that both the design margins and safety systems are adequate to provide effective mitigation if significant flow bypass were to occur.

The applicant stated that the SASS was designed to support the TSV hydrostatic loading during steady-state operation, in addition to the expected dynamic loading that would result from seismic activity. The SASS is also anchored to the surrounding system through supports to the dump tank. The applicant indicated that the design of the SASS was developed to support the safe operation of the TSV during all modes of operation by stating that it is a coherent structure that maintains its safety-related functions during anticipated design-basis stresses. These stresses are the result of expected hydrodynamic loads, temperature gradients, and irradiation. In addition, the SASS and associated piping and connections were designed to accommodate the typical displacements that would occur during normal operation and design basis transients, without degrading their capability to contain the target solution. The applicant addressed the interface design of the SASS with its associated piping and connections. The SASS is supported on top of the dump tank and aligned with the neutron drive with anchorages to the IU floor. The SASS was also developed with standard materials that have been shown by testing and experience to be compatible with the expected fluences, and to also accommodate the lifetime of the TSV without significant degradation.

The NRC staff finds that the SASS conforms to a geometrically sound support structure that maintains its functional shape during normal operation and transients. The staff also finds that the SASS is designed with customary materials that do not degrade significantly during the operational life of the TSV. The staff finds that the SASS is designed to serve as a fission product boundary in the event of a fission product breach by operating at a higher pressure than the TSV. Finally, the staff finds that the SASS can accommodate the expected hydrodynamic loads of the piping that it will encounter during operation.

Based on the information provided in the SHINE FSAR, the NRC staff finds that the SASS design basis meets the applicable acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4a.4.2.6 Neutron Multiplier

The NRC staff evaluated the sufficiency of the neutron multiplier, as presented in SHINE FSAR section 4a2.2.6, “Neutron Multiplier.” While the ISG augmenting NUREG-1537 does not have a section dedicated to the neutron multiplier, which is unique to the SHINE facility, the staff applied parts of the guidance from section 4a2.2.3, “Solid Neutron Moderator and Neutron Reflector,” of the ISG augmenting NUREG-1537 to its review of the neutron multiplier. Those portions of the guidance that are relevant to the structural-mechanical properties of the neutron multiplier, and not its functional properties, were applied. For the functional properties of the neutron multiplier (i.e., the increasing of neutrons for the target solution), the staff assessed whether the applicant provided information that satisfies the requirements of 10 CFR 50.34(b)(2).

The applicant stated that the neutron multiplier is an annulus of aluminum-clad material that moderates and multiplies the fast neutrons from the fusion reactions initiated by the neutron driver. The neutrons are multiplied through fission reactions. The design lifetime is 30 years, but the neutron multiplier can be removed and replaced if damaged. The construction materials for the neutron multiplier are compatible with the chemical and radiation environment. The heat generation rate in the neutron multiplier is expected to be approximately 15 kW during normal operation. The neutron multiplier is cooled by the PCLS and a breach of the aluminum cladding will be detected by the detection of radiation in the PCLS cooling water.

SHINE FSAR section 4a2.2.6 states that the neutron multiplier is designed to operate within the IU environment (i.e., at high temperature and irradiation). The multiplier cladding is thick enough to absorb fission fragments and to accommodate radiation damage, burnup, and heating. The mechanical and nuclear properties are not expected to degrade significantly during the multiplier's 30-year lifetime, and the mechanical/nuclear design bases are clearly presented. The manufacturing/machining process for the multiplier is also clearly described. The possibility of small failures of the mechanical integrity of the multiplier is also considered, with steps taken to accommodate mechanical degradation. For the case of cladding failure, the TSV can be safely shut down and the multiplier replaced. There are engineered features of the system to arrest deflagration with hydrogen produced from the cladding. Additional details were provided by letter dated June 17, 2020, that discuss the generation of hydrogen if the TSV solution were to leak into the cooling water and from water reacting with the natural uranium in the multiplier if there was a breach of the cladding. In both cases, the amount of hydrogen generation is expected to be less than what would be produced by radiolysis during normal operation of the IU. If the cladding were to fail, resulting in the contamination of the PCLS, then radiation monitors would detect the breach and actuate the TRPS trips of the PCLS circulation and IU shutdown. The primary, nuclear function (neutron multiplication properties) does not degrade with burnup.

The NRC staff finds that, per the ISG augmenting NUREG-1537, Part 2 evaluation criteria, the presented design describes a mechanically sound neutron multiplier that will allow for the safe operation of the TSV during the irradiation mode (Mode 2). Additionally, per 10 CFR 50.34(b)(2), the neutronic function of the multiplier will not significantly degrade with operation.

Based on the information provided in the SHINE FSAR, the NRC staff finds that the neutron multiplier design basis meets the applicable regulations and acceptance criteria for the issuance of an operating license.

4a.4.2.7 Conclusion

The NRC staff finds that the target solution and its expected chemical makeup, along with the expected interactions between the target solution and the PSB, are described in detail and are consistent with the historical data described in SHINE FSAR section 4a2.2.1.13. The operating conditions and chemical and physics properties of the target solution are described in detail.

The NRC staff finds that the design of the SASS is composed of appropriate materials known to be compatible with the expected chemical and radiation environment. It is designed to withstand the design-basis loads and provides sufficient cooling to the TSV and neutron multiplier.

The NRC staff finds that the SHINE FSAR contains detailed discussions on all major systems and components. These include the subcritical multiplication source, the neutron multiplier, the light water pool, the behavior of the TSV during a credible deflagration event, and the target solution qualification program.

Based on the above, the NRC staff finds that the description of the subcritical assembly and its components, including operating limits and operating conditions, is adequate. The subcritical assembly and its components are sufficient to ensure the health and safety of the public. Therefore, the staff concludes that the subcritical assembly and its components meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.3 Neutron Driver Assembly System

The NRC staff evaluated the sufficiency of the NDAS, as presented in SHINE FSAR section 4a2.3, “Neutron Driver Assembly System.” While the ISG augmenting NUREG-1537 does not have a section dedicated to the NDAS, is unique to the SHINE facility, the staff assessed whether the applicant provided information that satisfies the requirements of 10 CFR 50.34(b).

The applicant stated that the NDAS is an accelerator-driven system that produces 14.1 MeV neutrons via deuterium-tritium fusion reactions. The neutron driver produces a maximum of 1.5e14 neutrons per second. The high-energy neutrons move from the NDAS target chamber to the natural uranium neutron multiplier and then to the target solution to drive the subcritical fission reactions. The NDAS is situated above the subcritical assembly and mounted to the IU cell wall. It is part of the primary tritium system boundary.

The applicant stated that the operational life expectancy of the NDAS is primarily affected by radiation damage resulting from neutron activation of its components. Approximately 90 percent of the activity resulting from activation will be located beneath the pool surface. It is expected that most NDAS components will not experience significant radiation damage. Complex electronic components will be located outside the IU. The NDAS is a component that is designed to undergo maintenance and replacement of parts over the life of the SHINE facility.

4a.4.3.1 Neutron Driver

SHINE FSAR section 4a2.3.1, “Neutron Driver,” states that the neutron driver is contained within the IU cell and is made up of the accelerator section, the pumping stages, and the target section. The components are shown in SHINE FSAR figure 4a3.3-1. The accelerator section ionizes deuterium gas and accelerates the ions and transports them through a drift tube to the target section. The accelerator section is inside a pressure vessel that contains sulfur hexafluoride gas as an electrical insulator. The pumping stages maintain a high vacuum in the drift tube and return gas that escapes the target chamber back to the target chamber. The target section contains a mixture of deuterium and tritium gas and is where most of the deuterium-tritium fusion reactions occur. It has a water-cooling system.

4a.4.3.2 Neutron Driver Support Equipment

SHINE FSAR section 4a2.3.2, “Neutron Driver Support Equipment,” states that the neutron driver support equipment consists of a high voltage power supply (HVPS), a cooling cabinet, and control cabinets located outside the IU. The HVPS operates at 300 kilovolts and is considered in the facility fire hazard analysis. The cooling cabinet contains components of the cooling system for the NDAS cooling system. The NDAS cooling system is a closed loop system and it transfers heat to the radioisotope process facility cooling system (RPCS) though a heat exchanger. The control cabinets contain electrical power equipment, signal equipment, and control logic equipment. They interface with the normal electrical power supply system for electrical power and the process integrated control system (PICS) for control functions.

4a.4.3.3 Operation Overview

SHINE FSAR section 4a2.3.3, “Operation Overview,” states that the tritium and deuterium gas is supplied to the NDAS by the TPS. When the accelerator is turned on, deuterium ions are accelerated into the target chamber that contains a mixture of deuterium and tritium gas. The deuterium-tritium fusion reactions produce 14.1 MeV neutrons. These high-energy neutrons are multiplied in the natural uranium neutron multiplier and then enter the target solution and drive the subcritical fission reactions. The deuterium and tritium gas is sent back to the TPS for purification after irradiation operations are completed.

4a.4.3.4 Control System

SHINE FSAR section 4a2.3.4, “Control System,” states that the control system is the interface for the NDAS. It provides the means to energize, monitor, and change the state of the NDAS components including shutting down the neutron driver after a safety system trip. A two-key interlock on NDAS operation prevents operation when personnel are present in the IU cell or the neutron driver service cell as specified in TS LCO 3.8.5.

4a.4.3.5 Tritium Design

SHINE FSAR section 4a2.3.5, “Tritium Design,” states that the deuterium and tritium in the NDAS is supplied by the TPS and exhausted to the TPS after operation. The NDAS components containing tritium are maintained at low pressure by a vacuum system so that any leaks would be into the system. The NDAS is designed so that no single failure can result in an uncontrolled release of tritium.

4a.4.3.6 Seismic Design

SHINE FSAR section 4a2.3.6, “Seismic Design,” states that the NDAS components within the IU are classified as Seismic Category II to prevent damage to the IU’s safety-related equipment by components from the neutron driver during and following a design basis seismic event. The NDAS cooling system isolation valves and piping between the isolation valves and the primary confinement boundary are classified as Seismic Category 1 to maintain integrity of the primary confinement boundary during and following a design basis seismic event.

4a.4.3.7 Target Chamber

SHINE FSAR section 4a2.3.7, “Target Chamber,” states that the target chamber is maintained at low pressure and filled with a deuterium and tritium gas mixture. Because reactions between the ion beam and the gas cause most of the ion beam to be stopped before reaching the bottom of the target chamber, increases in target chamber pressure have insignificant effect on neutron yield. Decreases in target chamber pressure result in lower neutron yield. The target chamber pressure is limited by proposed TS LCO 3.8.6 to ensure that the amount of tritium in an IU cell is below the limit described in SHINE FSAR section 13a.2.2.12.1. The target chamber is cooled by the NDAS cooling system. It is surrounded by the subcritical assembly and is, therefore, subject to high neutron flux. The construction materials were chosen to mitigate the effects of corrosion and neutron damage.

4a.4.3.8 Conclusion

The NRC staff finds that the descriptions of the components of the NDAS satisfy the requirements of 10 CFR 50.34(b). The staff finds that the failure of any component of the NDAS would conservatively result in a decrease in fission rate. Additionally, safety related trips from the TRPS system would cause a shutdown of the neutron driver. The staff finds that there is a two-key lockout system that prevents operation of the neutron driver when personnel are present in the IU cell or the neutron driver service cell. Further, the NDAS is designed to prevent an uncontrolled release of tritium from any single failure and to prevent damage to any IU cell safety-related equipment during and after a design basis seismic event. Therefore, the staff concludes that the NDAS and its components meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.4 Target Solution Vessel and Light Water Pool

The NRC staff evaluated the sufficiency of the TSV and light water pool, as presented in SHINE FSAR section 4a2.4, "Target Solution Vessel and Light Water Pool." While the ISG augmenting NUREG-1537 does not have a section dedicated to the target solution vessel, which is unique to the SHINE facility, the staff assessed whether the applicant provided information that satisfies the requirements of 10 CFR 50.34(b).

The light water pool serves multiple functions, including heat removal and radiological shielding. The TSV is part of the PSB, which comprises the TSV, the TSV dump tank, and the TOGS. The TOGS is described in SHINE FSAR section 4a2.8.

4a.4.4.1 Target Solution Vessel

SHINE FSAR section 4a2.4.1, "Target Solution Vessel," describes the physical characteristics of the TSV, including the physical dimensions of the TSV and supporting structures. SHINE FSAR section 4a2.4.1.1, "Design Considerations," also states that the TSV is designed and fabricated in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, section VIII, Division 1. The TSV construction material is 347 stainless steel, and it has high corrosion resistance to the target solution environment, so no significant chemical damage is expected. The TSV will be monitored for corrosion with both visual inspections and corrosion coupons. The TSV is designed to last for the lifetime of the SHINE facility and is not expected to be replaced. Some of the piping is 304L and 316L stainless steel. Research performed at ORNL, LANL, and Argonne National Laboratory (ANL) on TSV construction materials during facility-relevant conditions were used to inform the final TSV design. The TSV penetrations and connections are described in SHINE FSAR section 4a2.4.1.4. Additional details about the penetrations and connections are provided in SHINE's letter dated June 17, 2020, including whether the penetrations are liquid or gas-filled during normal operation.

The applicant stated that the work performed at ANL shows that some fission product compounds are likely to reach solubility limits, but that they will be present in small enough quantities that their cumulative effect on reactivity is expected to be negligible. While SHINE plans to use catalytic agents to prevent the precipitation of uranium from the target solution, no catalytic agents will be used to mitigate the precipitation of fission product compounds.

The applicant stated that a TSV can be emptied into a criticality-safe TSV dump tank via the TSV dump valves. There are two completely independent dump valves, along with independent dump lines and overflow lines. These valves can be opened by the TRPS and fail in the open position. There are redundant flow paths to meet single failure criteria and to satisfy the second specification of proposed TS DF 4.3.2. Proposed TS LCO 3.1.5 requires that the TSV dump valves open within 2 seconds of demand, and that each dump line must drain the TSV from greater than or equal to the minimum target solution fill limit within 183 seconds. Proposed TS Surveillance Requirement (SR) 3.1.5 requires quarterly verification that a TSV drains within 183 seconds when it is greater than or equal to the minimum target solution fill limit. Leakage of the TSV dump valves during operation can be detected and would lead to a shutdown of the IU by the TRPS as specified in the low-high TSV dump tank level setpoint in proposed TS LCO 3.2.3.

The applicant stated that the TSV is designed to be resistant to chemical corrosion and neutron damage. The TSV has a 30-year design life and, as described by letter dated January 28, 2022, it will be subject to a periodic inspection and surveillance program designed to monitor corrosion and radiation damage. Also, by letter dated January 28, 2022, SHINE provided information to show that the high energy neutrons are largely thermalized in the region of the TSV, which confirms that the neutron spectrum is not significantly harder than the irradiation used for determining the neutron radiation damage limits because of the 14.1 MeV neutron source. Therefore, the design data used to assess radiation damage effects is applicable.

In its response to NRC staff RAI 4a-16 by letter dated January 28, 2022, SHINE demonstrated that the supplemental corrosion testing performed at ORNL was conducted over a range of test conditions expected to be representative of both normal operating and off-normal conditions at the SHINE facility as defined in the design basis. These tests evaluated corrosion characteristics over a wide range of electrochemical conditions, examined erosion-corrosion and potential cavitation effects, studied the effects of radiolysis on corrosion, and evaluated the effects of irradiation on key material properties. These tests support the assurance that the design requirements will be maintained over the TSV and SASS operating lifetimes and that the potential effects of material degradation over the design life have been sufficiently evaluated.

In conjunction with the testing performed at ORNL, SHINE described its surveillance and inspection plans in the response to RAI 4a-18. SHINE plans to insert corrosion, tensile, and fracture specimens into the TSV at several prescribed elevations and orientations. Nine specimen-withdraw times are planned over the 30-year design life of the TSV. Each withdrawal will remove and evaluate one corrosion coupon, two tensile specimens, and one fracture toughness specimen. The testing of the withdrawn coupons and specimens will allow a direct comparison between corrosion rates and mechanisms occurring within the TSV and allow trending of the mechanical property and fracture toughness behavior as a function of both operating time and irradiation fluence. The first specimen withdrawal will occur early in the life of the facility, at 1 effective full power year, to ensure that accelerated degradation is not occurring. Subsequent withdrawal times will be informed by the prior results to ensure both that property trends can be appropriately monitored, and that sufficient surveillance material will remain for evaluating properties at the end of the design life.

Boroscopic visual inspections of the TSV and SASS structures will also be performed periodically through access ports to examine the inner TSV surfaces that are most likely to experience degradation including weld locations, the liquid level line, piping connections, areas with the expected highest likelihood of chemical damage, areas experiencing the highest radiation fluence, and areas most likely to be subject to pressure pulses. Weld locations and mechanical locations of the SASS will also be visually inspected. As with the surveillance plan, the inspection plan and periodicity will be updated based on the surveillance and inspection findings.

Based on the above, the NRC staff finds that SHINE has an adequate program to monitor TSV radiation and corrosion damage over the life of the facility.

4a.4.4.2 Light Water Pool

SHINE FSAR section 4a2.4.2.1 states that the light water pool associated with each IU is constructed from concrete and lined with stainless steel and is designed to withstand the chemical environment of the target solution. Each pool contains approximately 19,000 gallons of water. The pool and the pool liner are designed as Seismic Category I structures to remain functional after a design basis earthquake. The nominal pool height is 15 feet relative to the bottom of the pool. The pool provides cooling and shielding. The SASS and TSV are located inside the light water pool, with the top of the TSV 5.3 feet (ft) below the water's surface under normal operating conditions. The pool also acts as a neutron moderator and reflector. In the event of a leak of target solution into the pool, the IU cell would be shut down and the light water pool system would pass the contaminated water through an ion exchange bed. If the degree of contamination were to exceed the cleanup capacity of the ion exchange beds, then the contaminated water would be processed by grouting and processing as low level waste. Piping penetrations to the light water pool are either above the minimum pool level or have anti-siphon devices or other means to prevent draining the pool below the minimum level.

SHINE FSAR section 4a2.4.2.2 states that the light water pool provides decay heat removal from the TSV dump tank after the target solution is drained from the TSV. The light water pool also provides about 5.5 kW of heat removal during irradiation of the target solution. The light water pool transfers heat from the PCLS through natural convection heat transfer. The light water pool also provides a heat sink with large thermal capacity for shutdown cooling after a postulated accident.

Proposed TS LCO 3.3.1 specifies that the light water pool minimum level as 14 ft relative to the bottom of the pool to ensure adequate cooling and shielding. The pool level is verified to be above the minimum level before entering Mode 1 (Startup). If the pool level goes below the minimum level during Mode 1 (Startup) or Mode 2 (Irradiation), then the dump valves are opened, and the target solution drains to the TSV dump tank to transition the IU to Mode 3 (Shutdown) and then finally to Mode 0 (Solution Removed).

4a.4.4.3 Conclusion

The NRC staff finds that the descriptions of the TSV and the light water pool satisfy the requirements of 10 CFR 50.34(b). The staff finds that the TSV is conservatively designed to fail to a safe, non-critical geometry and that its components are adequately designed to withstand credible accidents and the normal operating environment. The staff also finds that the light water pool provides cooling to the TSV, biological shielding, and shielding to prevent radiation damage to SSCs in the IUs. Therefore, the staff concludes that the TSV and the light water pool meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.5 Irradiation Facility Biological Shield

The NRC staff evaluated the sufficiency of the irradiation facility biological shield, as presented in SHINE FSAR section 4a2.5, “Irradiation Facility Biological Shield,” using the guidance and acceptance criteria from section 4a2.4, “Biological Shield,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The applicant stated that the irradiation cell biological shield is designed to protect workers and members of the public from radiation sources in the IF. Shielding is provided through concrete enclosures for the IU cells and the TOGS shielded shell that vary in thickness from approximately 4 to 6 ft. The concrete walls that vary from approximately 0.7 to 1 ft thick and the steel doors that are approximately 3 in. thick act as a shield on the primary cooling room. SHINE FSAR figure 4a2.5-1 shows different section cuts through the biological shield. The dose rates on the external surfaces of the shields are designed to be less than 1 milli-roentgen equivalent man per hour.

The applicant stated that the biological shield is designed to meet the as low as (is) reasonably achievable (ALARA) radiation exposure goals described in chapter 11 of the SHINE FSAR and to meet or exceed the requirements in 10 CFR Part 20. The applicant proposed to use a newer concrete standard, American Concrete Institute (ACI) 349-13, “Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary,” than the one specified in Regulatory Guide (RG) 1.69, Revision 1, “Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants” (ML090820425), which is ACI 349-06. The applicant used this standard in a way that is consistent with how ACI 349-06 is used in RG 1.69. The proposed materials and configuration are consistent with NRC staff-endorsed guidance.

To evaluate the effects of concrete degradation due to neutron and gamma radiation, the applicant estimated fluence to the concrete and the corresponding dose at that location with the Monte Carlo N-Particle Transport Code (MCNP) according to NUREG/CR-7171, “A Review of the Effects of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants” (ML13325B077). Fluxes and dose rates were evaluated at various points of the shield structure. As a result of this analysis, the applicant showed that concrete radiation degradation and nuclear heating is not significant over a 30-year operating lifetime. For those locations that accumulate stress concentrations and for which statistically valid flux tallies are difficult (penetrations and interfaces), a shielding program will be put in place and managed as described in SHINE FSAR section 11.1. The shields are constructed according to rigorous standards, such that they remain intact during normal operating conditions and design basis accidents. One unique feature of the SHINE design is the use of 14.1 MeV deuterium-tritium fusion neutrons for the neutron driver. SHINE provided information regarding the adequacy of the shield for these high energy neutrons by letter dated June 17, 2020.

The applicant stated that the radiation fluence to the inside of the shield is well within the allowable standard for the life of the shield. Nuclear heating in concrete can be neglected if energy fluxes are less than 1.0e10 MeV per square centimeter per second or if temperatures are kept lower than 149ºF. The energy fluxes in the concrete are below this limit in all areas except for the concrete directly below the TSV dump tank, where there was a calculated maximum energy flux of 6.0e10 MeV per square centimeter per second. However, the light water pool provides adequate cooling of this concrete to keep the temperature of the concrete below 149°F.

The NRC staff finds that SHINE used conservative values for gap sizes in how the plugs fit and that penetration sizes to conservatively account for streaming will ensure that the biological shield design will limit radiation exposure from the IF to workers and the public.

The NRC staff finds that the results of the analyses presented in the SHINE FSAR show that the biological shield meets all regulatory requirements. Therefore, the staff concludes that the biological shield meets the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.6 Nuclear Design

The NRC staff evaluated the sufficiency of the IF nuclear design, as presented in SHINE FSAR section 4a2.6, “Nuclear Design,” using the guidance and acceptance criteria from section 4a2.5, “Nuclear Design,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

The IU is comprised of the biological shield, the NDAS, the light water pool system, the SCAS, and the NFDS. The IU’s supporting systems include the TOGS, the TPS, and the PCLS. The IF contains eight IUs and each IU is supplied with deuterium and tritium by the TPS. Each of the three TPS trains supports a specified set of IUs. This section evaluates the nuclear parameters and characteristics of the IF to determine whether it can be operated and shut down safely from any operating condition.

4a.4.6.1 Normal Operating Conditions

The NRC staff reviewed the sufficiency of SHINE FSAR section 4a2.6.1, “Normal Operating Conditions,” using the guidance and acceptance criteria from section 4a2.5.1, “Normal Operating Conditions,” of the ISG augmenting NUREG-1537, Parts 1 and 2. Given that the TSV configuration operates in a sub-critical mode, those criteria that are relevant to a subcritical system with no excess reactivity were adapted for use with SHINE.

SHINE FSAR section 4a2.6.1 describes a subcritical assembly that can operate safely and be shut down and remain shut down through the TRPS and associated TSV dump tank. The design information, as supported by tables and figures, demonstrates that the chemical and physical properties of the target solution are accounted for in the reactivity balance of the system. The physical design configuration is described. The chemical and physical properties of the system are clearly described and supported with associated tables and references. The variables that influence reactivity are identified and calculated; some of these variables are monitored and controlled to be in specified ranges. The NRC staff also reviewed the sections of SHINE FSAR chapter 13 that consider reactivity additions of water due to malfunction of the TOGS or due to failure of the pressure boundary. The means to introduce target solution to the system (through the vacuum transfer system) are actively controlled by the operator, and don’t allow the passive addition of extra solution to the TSV.

The applicant also calculated a bounding, worst-case limiting core configuration (during Mode 1 startup), along with the corresponding subcritical multiplication margin. The associated volume margins to criticality were calculated and described in the SHINE FSAR, and additional margins that allow for the return of TOGS condensate to the target solution were also calculated and subtracted from the operating volume. During startup (Mode 1), the subcritical multiplication source allows flux detectors to monitor the reactive increase of the assembly. The target solution chemical and physical state is monitored and controlled prior to startup.

The applicant determined that the limiting case (in terms of margin to criticality) occurs at the point of maximum fill height right before the transition to Mode 2 (i.e., before the start of irradiation), enveloping all other conjectured configurations. Proposed TS limiting safety system setting 2.2.3 sets a source range neutron flux limit; this protects against a sudden increase in reactivity during the fill process.

The application states that all reactivity components of the system were calculated to inform the design, operation, safety features, and protection systems of the SCAS. Changes in reactivity with uranium burnup, plutonium buildup, fission product poisons, radiolytic gas-void formation, TOGS sweep-gas pressure regulation, TOGS condensate return, PCLS water temperature changes, solution temperature changes, neutron multiplier burnup, and neutron multiplier temperature are calculated and accounted for in the target solution startup and irradiation strategy. The target solution chemistry doesn’t change significantly with burnup. For this reason, there are no reactivity changes associated with changes in target solution pH or catalyst concentration. There are reactivity changes corresponding to uranium concentration changes (reactivity components are also presented as an equivalent uranium concentration), but this concentration does not substantially change during an irradiation cycle. The reactivity effects of transmutation and fission products are calculated by the applicant. In the case of fission products, the major contributor, plutonium, is managed by extraction through the MEPS. Although the gaseous fission products from solution are extracted through the associated cleanup and safety systems, their bounding reactivity effects are calculated and compared to the other components for both startup and irradiation. The steady-state evolution of core reactivity, and the contribution of each component, is explicitly calculated, with the total batch target solution age being divided into alternating irradiation/shutdown cycles. As the target solution operates subcritical, there are no chemical poisons or mechanical components that are designed to hold down excess reactivity. There is not an associated reactivity change due to the static nature of the mechanical components. There is a holdup of water within the TOGS active gas management system. The volume of this water holdup and its associated reactivity effect are also calculated. The actions of the TOGS have several reactivity effects that were considered by the applicant, specifically, due to the TSV head-space pressure regulation (sweep and purge actions) and the uranium concentration effect of the target solution gaining or losing condensate. The positive reactivity effect resulting from water holdup in TOGS is accounted for when the minimum subcritical volume of the target solution is determined.

The applicant stated that to compensate for uranium burnup and target solution processing at the end of each irradiation cycle, the solution is adjusted before transfer to the TSV. Administrative controls are applied to ensure that the solution temperature, uranium concentration, solution chemistry, pH, catalyst, and solution volume are within acceptable levels prior to transfer to the TSV.

The applicant stated that several drastic core configuration and component scenarios were evaluated in terms of static reactivity changes for the startup and irradiation modes: water flooding of the head-space volume above the target solution; driver target flooding; neutron multiplier flooding (assuming a cladding breach); voiding of PCLS; and a total loss of pool water. The limiting core configuration that would give the highest power densities in terms of uranium concentration, batch size, and fill height was also calculated.

The applicant used the TRIAD code to calculate coupled system behavior by considering the total impact on the target solution with three induced transients. Reactivity effects of void collapse were considered along with peak power change relative to nominal power. The applicant’s analysis demonstrated that power changes could be accommodated through natural self-dampening effects of the negative target solution coefficients (temperature and void). Coupled system oscillations are anticipated due to beam variations (normal beam interruptions), the TOGS pressure variations, and the PCLS temperature variations. The transients induced by the NDAS beam interruptions were analyzed by the applicant. To preclude over-cooling (and, in turn, reactivity increase) of the target solution in the TSV that would occur with a temporary NDAS beam interruption, the TRPS limits the time duration over which this beam interruption could occur by opening the HVPS breakers after a time delay, depending upon the source strength. This protection is discussed in SHINE FSAR section 7.4.3.1.4. This limits the amount of the calculated peak power change during the transient such that operational power limits aren't reached. Similarly, the change in fission power due to the TOGS pressure oscillations and the PCLS temperature changes are also calculated. These transients do not go beyond operational limits.

SHINE has an administrative program and engineering DFs that form the bases of TSs, and envelope the normal and transient behavior of the TSV related to uranium concentration, target solution chemistry, NFDS flux setpoints, allowable fill volumes and solution heights, trip setpoints, solution fill rates, and delay times for opening of dump valves. These values inform proposed TS SRs and LCOs.

SHINE developed administrative, procedural, and engineering barriers to prevent the unwanted addition of reactivity during all operational modes. Except for the engineering barriers (which are binned as the natural physics of the negative temperature coefficients and are part of the design), the other barriers were put in place to keep the solution under control for all anticipated operational states and transients.

SHINE FSAR section 4a2.6.1 states that the SCAS operates under three modes that are relevant to nuclear design: Mode 1 (startup); Mode 2 (irradiation); and Mode 3 (post-irradiation). A fourth mode (solution removed) is described in SHINE FSAR chapter 7 and is not discussed in Chapter 4. In each of these three modes, the IU can be shut down by the TRPS, which will trip on high neutron flux and high PCLS temperature. As an additional, administrative control, the operators can manually dump the contents of the TSV to the TSV dump tank, although these measures are not required for safe shutdown or operation. When shutdown, the neutron driver is de-energized and the target solution is held in a criticality-safe geometry TSV dump tank. Proposed TS LCO 3.1.8 specifies the time that the target solution is required to be held in the TSV dump tank before being transferred to the RPF. This hold time depends on the maximum irradiation power level and limits the radionuclide inventory and source term for the RPF accident analysis. There are two completely independent TSV dump valves, along with independent dump lines and overflow lines. The TSV dump valves fail open and can be triggered by the TRPS, PICS, and the operator. SHINE provided additional details describing the drain rate, trip signal delay, and valve opening time by letter dated June 17, 2020.

The applicant stated that the burn-up after the designed amount of exposure of the target solution is minimal. The effect of Xenon and Samarium accumulation is estimated to result in a power reduction of less than 10 percent relative to a system without Xenon and Samarium.

The final design describes the reactivity and reactivity changes of the system during all modes of operation, including reactivity worth of the IU components for each mode of operation, the worth of water held up outside the TSV and the effects of removing that water, and expected changes in reactivity that would occur due to voiding of the cooling system. The system interfaces with the PICS and TRPS to shut down on abnormal conditions (e.g., loss of power, high flux, high hydrogen concentration). The physical and administrative controls that are designed to prevent criticality from occurring are sufficient to protect workers and the public from potential criticality accidents.

The SHINE FSAR states that minor power oscillations during operation are expected due to flow fluctuations and strong void feedback based on AHR operating experience, but that these oscillations would be small and self-limiting due to the low power density and negative void and temperature coefficients. In the case of a TOGS failure, the resulting void collapse would cause a small reactivity increase, but not one large enough to result in criticality.

4a.4.6.2 Target Solution Physics Parameters

SHINE FSAR section 4a2.6.2.1, "Analysis Methods and Code Validation," states that a variety of computer codes are used to calculate nuclear physics parameters. MCNP5 is used to calculate neutron flux, reactivity, dose rates, neutron lifetime, and reaction rates. MCNP5 is publicly available and widely used in the nuclear industry for modeling neutron-nuclear interactions with matter. SCALE (Standardized Computer Analysis for Licensing Evaluations) is a comprehensive modeling and simulation suite for nuclear safety analysis and is capable of performing calculations for reactor physics, criticality safety, and radiation shielding. COUPLE, a module of SCALE, is used to calculate flux-dependent cross-sections and fission yields (COUPLE is not an acronym and references the functionality of the module – it "couples" nuclide decay terms in the master transition matrix with the functional ORIGIN library). Oak Ridge Isotope Generation (ORIGIN), a module of SCALE, is used to generate source term concentrations and activities following various irradiation and decay intervals. By letter dated June 17, 2020, SHINE provided uncertainty analysis for the calculations using these codes. To demonstrate its applicability for uranyl sulfate solution reactors, SHINE compared MCNP5 to a published suite of aqueous solution reactor benchmark cases. From this assessment, the MCNP5 calculated bias and bias uncertainty of system multiplication factor (one-sided tolerance limit) was determined with a standard methodology, NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology" (ML050250061), and was applied to the analysis of the TSV dump tank and TOGS. MCNP5 was compared to experiments for similar systems to evaluate the applicability of MCNP5 to the solid uranium metal multiplier and found acceptable by the applicant. The SCALE and MCNP5 packages are maintained at Department of Energy facilities under separate configuration management plans.

Using MCNP5, SHINE evaluated all significant contributors to reactivity for the range of solution burnup and for all relevant operational modes. Two-sided tolerance bands at a 95th percentile probability with a 95th percentile confidence limit (95/95) with conservative assumptions were used to quantify the uncertainty of reactivity coefficients and neutron multiplication with respect to uncertainties in state parameters. SHINE established that the total reactivity and power coefficients were sufficiently negative over the range of expected system conditions and that burnup had little effect on power distribution, flux, and reactivity coefficients of the target solution. Kinetics parameters such as neutron lifetime and the effective delayed neutron fraction for both fresh target solution and end of life target solution were also calculated. Reactivity coefficients for the target solution and multiplier were evaluated at different target solution temperatures and uranium concentrations. Uranium concentration, flux density, and power peaking were calculated at both nominal and limiting conditions, along with the corresponding reactivity coefficients.

SHINE stated that the calculations show that target solution void, temperature, and power coefficients will generally be negative for all modes of operation. They are in the range of other operational AHRs and conceptual designs. The temperature and void coefficients for the PCLS are positive, but the applicant's calculations show that this will not result in strong positive feedback because the TSV feedback is dominant. The PCLS is not expected to have significant voiding and the water volume is limited in the narrow TSV cooling paths. The target solution void and temperature coefficients are the most significant because the radiolysis gas and because the majority of the heat is deposited directly into the target solution. Analyses show that the combined reactivity coefficients are sufficiently negative over the anticipated range of operating conditions.

SHINE performed transient analysis with the TRIAD code, which is an extension of a LANL systems code that was developed to model an AHR that is coupled to a neutron-accelerator system (A Generic System Model for a Fissile Solution Fueled Assembly, LA-UR-13-22033, Los Alamos National Laboratory, Kimpland, R., Klein, S., 2013). It is a 1D fluid flow model and has an empirical void transport model. The actual void distribution is determined by a buoyancy driven natural circulation flow pattern that depends on the power void and temperature profiles in the TSV and cannot be mechanistically predicted by the TRIAD code. SHINE performed a group of calculations in which the empirical void transport model was changed over a wide range. The results of the steady state and transient calculations are sensitive to the void transport model. The coefficients can be tuned to improve the fidelity of TRIAD code predictions. By letter dated June 17, 2020, SHINE described the extensions made to the LANL code and explained how TRIAD is validated against the Silene and KEWB (Kinetics Experiments on Water Boilers) experiments.

4a.4.6.3 Operating Limits

SHINE FSAR section 4a2.6.3, "Operating Limits," discusses specific values for operating limits. Void coefficients are negative throughout all operating conditions, and combined reactivity coefficients are sufficiently negative over the anticipated range of operating conditions. The target solution burn-up is minimal in the SCAS. The worth of fission product poisons such as Xenon and Samarium are small compared to the temperature and void defects.

The applicant stated that there are only three initiating events that may result in inadvertent insertions of excess reactivity: (1) excessive cooldown of the TSV; (2) increased pressure in the TSV; and (3) excess volume of target solution. None of these events result in damage to the PSB. These events are described in SHINE FSAR chapter 13, which the NRC staff reviews in chapter 13 of this SER. In the event of a loss of power to an IU, the neutron driver will de-energize and the target solution will be transferred to the criticality-safe TSV dump tank. Each IU has its own TSV dump tank.

4a.4.6.4 Conclusion

The NRC staff finds that SHINE FSAR section 4a2.6 provides an adequate description of the proposed configuration of the SCAS during the three relevant modes of operation. The staff determined that the target solution behavior during operation has been adequately addressed, including gaseous fission product buildup and removal, poisons, and power oscillations. The staff also determined that the reactivity analyses include reactivity values for the in-core components.

The NRC staff finds that SHINE's methodology for calculating the neutron lifetime, effective delayed neutron fraction, and coefficients of reactivity is acceptable. The staff finds that the code predictions for the ratio of neutron production to neutron absorption and leakage, reactivity coefficients, and reactivity worths of target solution changes are bound within an uncertainty band that is determined by code comparisons to experimental benchmarks.

Based on the above, the NRC staff finds that the descriptions of the nuclear design component of the SHINE facility satisfy the requirements of 10 CFR 50.34(b). Therefore, the staff concludes that these descriptions are sufficient and meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.7 Thermal-Hydraulic Design

The NRC staff evaluated the sufficiency of the thermal-hydraulic design, as presented in SHINE FSAR section 4a2.7, “Thermal Hydraulic Design,” using the guidance and acceptance criteria from section 4a2.6, “Thermal-Hydraulic Design,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

SHINE provided a description of the systems that are responsible for target solution inventory control, heat removal during irradiation, and shutdown operations for the eight IUs.

4a.4.7.1 Heat Removal Systems

SHINE FSAR section 4a2.7.1 states that the SHINE heat removal systems must have adequate capacity to remove heat during irradiation and shutdown operations. The paths for heat removal from the TSV are the PCLS and the TOGS. The light water pool is also cooled by the piping in the PCLS.

SHINE FSAR section 4a2.7.1.1 states that the PCLS cooling loop circulates water in an upward direction past the TSV heat transfer surfaces using forced convective cooling. Energy can also be deposited into the PCLS coolant by neutron and gamma radiation. The PCLS cooling water removes heat from the TSV and then the PCLS water flows to reject the heat through a heat exchanger in the RPCS.

The SHINE FSAR states that the PCLS cooling loop also removes heat from the light water pool, the neutron multiplier, and the neutron driver tritium target chamber using forced convective flow. The heat loads on the light water pool are energy deposition by neutron and gamma radiation from an operating IU and decay heat loads from the TSV dump tank when it contains irradiated target solution. The PCLS cooling water rejects heat to the RPCS.
During IU operations, the heat deposited in the light water pool is approximately 2 percent of the thermal power.

The SHINE FSAR states that the TOGS operates as a closed loop system in which nitrogen sweep gas is circulated above the top of the TSV liquid level. The gas is circulated through a flow loop that removes iodine from the off-gas, recombines radiolysis generated hydrogen and oxygen to keep them below flammable limits, and condenses water vapor and returns the liquid water to the TSV. Heat from the condensation and recombination processes are transferred through heat exchangers that ultimately reject heat to the RPCS.

4a.4.7.2 Cooling Water Hydraulic Characteristics of the TSV

SHINE FSAR section 4a2.7.3.1 states that the PCLS removes heat from the TSV during irradiation and shut down operations. The PCLS minimum volumetric coolant flow rate is adequate to keep the target solution temperature within allowable limits. The PCLS coolant water enters at 59 – 77°F and a pressure of 138 kilopascals (kPa). The flow rate is adequate to maintain the TSV at a temperature of 120°F during irradiation. The TSV pressure is maintained below the PCLS pressure to prevent leakage out of the TSV in cases where the PSB is breached. In the case of leakage of water from the PCLS into the TSV, the dilution of the target solution will lead to a negative reactivity insertion. If the breach is large enough such that the pressure difference cannot be maintained, then some of the target solution could leak into the PCLS cooling water. The nominal temperature of the target solution in the TSV is 68 – 140°F. The operating conditions in the TSV prevent the plating out of chemicals on the PCLS heat transfer surfaces

The applicant stated that a loss or degradation of the PCLS cooling system would cause an increase in the target solution temperature. If the PCLS coolant temperature or the target solution temperature rises above the allowable limit, the TRPS system will shut down the neutron driver and dump the target solution to the TSV dump tank where it will be cooled by natural convection in the light water pool.

The applicant stated that the light water pool is cooled by the pipes of the PCLS. If the PCLS is not operating, the light water pool has a large heat capacity that can be used to remove decay heat from the TSV dump tank for long periods of time without active cooling. Natural or free convection cooling on the outside of the TSV dump tank is adequate to maintain target solution temperatures within the tank below the 194ºF limit. The heat capacity of the pool is large enough that the pool temperature will remain well below the boiling temperature of water after 90 days of decay heat load at the minimum acceptable pool level for accident conditions.

4a.4.7.3 Target Solution Thermal Power Density Distribution

SHINE FSAR section 4a2.7.4 provides the power density distribution in the target solution. The fission power density has peaks in the axial and radial dimensions due to neutron transport effects. The radiolysis gas generation source is related to the fission power source since the primary mechanism for producing radiolysis gas is the fission fragments colliding with water molecules and causing dissociation of the water molecules. Neutron and gamma radiation can also be a source of radiolysis gas formation. The decay power distribution is not directly related to the fission power distribution since the fission products that are the source of decay power will circulate with the coolant. The thermal power density distribution drives gradients in fluid temperature and void fractions that enhance natural circulation in the target solution.

4a.4.7.4 Thermal-Hydraulic Calculations and Methodology

SHINE FSAR section 4a2.7.5 discusses a correlation-based thermal-hydraulic methodology for safety-related calculations involving fluid flow and convective heat transfer. The applicant stated that the calculations are used to estimate the steady state and transient target solution temperature which is determined by the balance of the heat generation and the heat removal to heat transfer surfaces by natural circulation flows caused by temperature and void fraction gradients. The results of experiments performed at the University of Wisconsin – Madison using electric heaters and bubble injection to simulate the effects of volumetric heating and gas generation were used to determine the expected range of heat transfer coefficients and void fractions. The experiments used magnesium sulfate to simulate the uranyl sulfate target solution. The data collected was used to form the basis of an empirical heat transfer coefficient. The heat transfer correlation has the form of a turbulent free convection correlation with the length scale implicitly embedded in the leading constant multiplied by a void fraction enhancement factor that could account for increased buoyancy driven flow. The enhancement factor is significant which implies that the buoyancy of the voids induces a large recirculating flow. SHINE calculated a void fraction to use in the heat transfer calculations using a bubble nucleation and growth model. A description of assumptions used in the calculation is in SHINE FSAR section 4a2.7.5.5. The heat transfer on the PCLS side of the TSV is single-phase water-cooling flow and the surface temperatures on the PCLS side are below the boiling temperature of the cooling water which eliminates the possibility of exceeding the critical heat flux.

4a.4.7.5 Impact of Operating Conditions on Thermal-Hydraulics

SHINE FSAR section 4a2.7.6 states that the heat removal and recombination capacities of the TOGS will determine the pressure of the gas space and target solution for a fixed TSV power. Feedback effects on the power generation will determine the operating power and pressure where there is a balance between the gas and water vapor generation in the TSV and the heat removal and recombination capacity of the TOGS if steady state operation is possible. It is also possible that the system may operate in an oscillatory mode with operating conditions that vary but stay within safety limits. SHINE provided a stability analysis of the accelerator driven system that was performed by LANL and documented in report LA-UR-14-28684, “Stability of Fissile Solution Systems.” The LANL stability analysis showed that the system is stable across the expected range of operation and that any oscillations are damped. Driven and bounded reactivity or source strength oscillations will also result in a bounded response. The target solution is expected to be stable with respect to chemical and physical properties during an irradiation cycle. Void formation in the target solution will be caused by radiolysis gas formation. The effects of the voids on nuclear and heat transfer performance of the system are accounted for in the final design. The void formation enhances the heat transfer in the TSV due to increased natural circulation flows due to buoyancy effects. The natural circulation also helps prevent large non-uniformities in temperature and solution concentration. Target solution pressure, temperature, pH, and solution concentration will be monitored and maintained throughout the cycle. The hydrogen concentration in the cover gas will also be monitored and maintained through the cycle.

4a.4.7.6 Cooling System Design Basis

The thermal-hydraulic design has systems described above that provide heat removal from the TSV. The cooling system design basis and details of the PCLS are provided in chapter 5 of the SHINE FSAR.

SHINE FSAR section 4a2.7.8 states that small amounts of radiolysis gases will be generated in the PCLS coolant since it is exposed to radiation from the TSV. The system is designed so that large pockets of gas will not accumulate and lead to significant void fractions in the region of the TSV.

4a.4.7.7 Bulk Boiling of the Target Solution

SHINE FSAR section 4a2.7.9 states that the temperature of the target solution is monitored. The temperature and flow of the PCLS loop is also monitored to ensure adequate cooling of the TSV. If temperature limits are exceeded, the TRPS system will shut down the neutron driver and dump the target solution to the TSV dump tank. This prevents boiling in the TSV. If boiling were to occur due to unforeseen circumstances, the target solution and off gases will still be confined within the PSB and will not present a radiation hazard.

4a.4.7.8 Conclusion

The NRC staff reviewed the thermal-hydraulic design of the IUs. The staff finds that the thermal-hydraulic design considers the dominant design considerations for heat removal, cover gas control, and target solution control. The staff also reviewed the heat removal system specifications and finds that SHINE has considered all significant heat loads and has provided adequate heat removal capacity and heat transfer area to remove the heat loads and maintain the TSV fluid under normal and abnormal conditions. Adequate heat removal is also provided for decay heat generation in the TSV dump tank. The staff finds that the heat transfer surface temperatures in the PCLS eliminate concerns about critical heat flux. The staff also finds that the TOGS has adequate recombination and condensation capacity to control the cover gas operating conditions and maintain them within normal operating parameters. Based on the above, the staff concludes that the thermal-hydraulic design of the IUs meets the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.8 Gas Management System

The NRC staff evaluated the sufficiency of the SHINE gas management system, as presented in SHINE FSAR section 4a2.8, “Gas Management System,” using the guidance and acceptance criteria from section 4a2.7, “Gas Management System,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

SHINE FSAR section 4a2.8 contains information about the TOGS. Each of the eight IUs has a TOGS. The TOGS removes radiolysis gases and a portion of the iodine in the gas space from the TSV during irradiation operation and during target solution cooldown. The safety function of the TOGS is to provide confinement of target solution and fission products, maintain hydrogen concentrations, and remove a portion of the iodine from the sweep gas.

SHINE FSAR section 4a2.8 states that the TOGS operates by circulating a sweep gas made up of nitrogen and oxygen through the TSV and TSV dump tank at a rate high enough to keep the hydrogen concentration below flammability limits (4 percent lower flammability limit) that can challenge the 65 pounds per square inch absolute (psia) deflagration pressure limit. The PICS controls the TOGS during normal operations. Nitrogen and oxygen can be added to the TOGS to control pressure and minimum oxygen concentration. The maximum operating pressure can be controlled by opening a valve to the vacuum tank. Each TOGS has two separate recombiner loops. There are some asymmetries between the loops. Only one loop provides flow to the TSV dump tank. Additionally, one loop has hydrogen and oxygen sensors and the other has a zeolite bed to capture iodine. Both loops must be operable during irradiation and one needs to operate for a short time after a loss of offsite power to reach a safe shutdown condition. The hydrogen recombiners prevent the concentration of hydrogen from reaching a level where a deflagration or detonation could occur. The water vapor in the sweep gas and from the recombiner is condensed and returned to the TSV. This serves to conserve water in the system since a loss of water will increase the uranium concentration in the solution and, therefore, increase the reactivity of the system. Water holdup in the TOGS is limited to 3 liters. The basis for the estimate of 3 liters and the identification of locations that water can be trapped in the TOGS were provided by letter dated June 17, 2020. Specifically, the TOGS circulates the sweep gas into the TSV dump tank and up through the overflow tubes into the TSV head space to prevent the moist atmosphere in the TSV headspace from flowing down the overflow tubes into the TSV dump tank, which might lead to condensation and loss of water to the TSV dump tank. If excess water does accumulate in the TSV dump tank, it will lead to a shutdown of the IU by the TRPS as specified by the low-high TSV dump tank level setpoint of 3 percent in proposed TS LCO 3.2.3. Water droplets in the sweep gas are also removed and returned to the TSV to minimize the buildup of fissile material in the TOGS. The TOGS maintains a gas space pressure that is below the IU gas space pressure. The TOGS is designed based on the following TSV operating parameters:

- Gas temperature: The range of temperatures for gas leaving the TSV headspace is based on the sweep gas supply temperature from TOGS and the heat transfer rate between the sweep gas and the target solution at a temperature range of 50°F (10 degrees Celsius (°C)) to 194°F (90°C).

- Gas pressure: -4.5 pounds per square inch gauge (psig) (-31 kPa gauge) to 15 psig (103 kPa gauge).

- Steady state hydrogen production rate: up to approximately 3.8E-2 grams/second.

- Relative humidity: The relative humidity for gas leaving the TSV headspace is based on the evaporation rate of the target solution at a maximum temperature of 194°F (90°C).

SHINE FSAR section 4a2.8.5 states that the TOGS also needs to be adequate to mitigate the design basis accidents analyzed in chapter 13 of the SHINE FSAR. The design pressure for the PSB, and therefore the TOGS, is 100 psi. The design temperature for most TOGS components is 200°F. The hydrogen recombiners, recombiner condensers, and the interconnecting piping have a design temperature of 650°F because the heat from the recombination of hydrogen and oxygen causes elevated temperatures in those TOGS components compared to the temperatures in the other TOGS components and the TSV.

The applicant stated that the construction materials used for the TOGS are compatible with the expected chemical environment and conditions, and that no credible scenarios would result in a loss of confinement because of corrosion. The geometry of the TOGS would preclude criticality even if it were filled with target solution.

The applicant stated that the hydrogen recombiner needs to be capable of preventing a hydrogen deflagration or detonation. Hydrogen and oxygen generation in the TSV is 33 standard liters per minute and consists of 2/3 hydrogen and 1/3 oxygen. The PICS will alert the operator of high hydrogen concentration if it reaches 2.5 percent by volume. This allows the operator to take action before the operating limit of 3 percent. In turn, the 3 percent operating limit provides sufficient margin to hydrogen concentrations (4 percent lower flammability limit) that could result in deflagration pressure exceeding 65 psia should the failure of a single active component occur. SHINE's analysis shows that this will provide sufficient margin to the lower flammability limit in the event of an abnormal condition such as a TOGS blower failure. The TOGS is designed to withstand system pressures expected during credible TSV power fluctuations.

The TOGS has interfaces with other systems. The TOGS system purges the off-gas to the vacuum transfer system (VTS) which discharges it to the process vessel vent system (PVVS) to prevent a buildup of gaseous fission products. The VTS and the PVVS are part of the RPF. In the PVVS, the off-gas is treated through the PVVS filters, guard beds, and charcoal delay beds, which remove particulates and iodine and delay the release of noble gases to the environment. The pressure safety valves in the TOGS are also connected to the PVVS. The TOGS is shielded to limit personnel exposure to radiation. The system does not release a significant amount of nitrogen oxide or sulfur oxide gas, therefore, no accident scenarios or monitoring for these gases are described in the SHINE FSAR.

By letter dated June 17, 2020, SHINE provided information describing the functionality and design basis functional requirements of the vacuum and pressure relief valve system. The design basis of the vacuum and pressure relief valve system is to keep the TOGS within a pressure range of -4.5 to 15 psig to allow continued functioning of the TOGS blowers. The lower limit is to protect against boiling in the TSV and the upper limit is to protect against an uncontrolled addition of gas from an external source. The relief valve is not needed to protect against exceeding the 100 psi design pressure of the TOGS during a deflagration event.

SHINE FSAR section 4a2.8.7 discusses the TRPS trip inputs related to the operability of the TOGS, which are:

- Low TOGS oxygen concentration
- Low TOGS mainstream flow (Train A)
- Low TOGS mainstream flow (Train B)
- Low TOGS TSV dump tank sweep gas flow
- High TOGS condenser demister outlet temperature (Train A)
- High TOGS condenser demister outlet temperature (Train B)

The SHINE FSAR states that the TRPS inputs are designed to protect against an inoperable TOGS train and loss of cooling to the condenser. If the TOGS becomes inoperable during an off-normal event such as a loss-of-offsite-power (LOOP) event, hydrogen buildup in the system is limited by the nitrogen purge system (N2PS), which injects nitrogen gas into the TSV dump tank to dilute the hydrogen and keep it below 3 percent by volume. During a LOOP event, TOGS Train A is powered by the uninterruptible electrical power supply system for 5 minutes. The N2PS injects nitrogen gas into the TSV dump tank after 3 minutes. The gas mixture is transferred to the PVVS through a high point vent on the TOGS.

The NRC staff finds that the operating condition envelope and design assumptions of the TOGS and the associated analysis are sufficient to provide reasonable assurance of safe operation of the SHINE facility and compliance with all applicable chemical and radiological release criteria. The staff finds that the TOGS and its components are sufficient to ensure the health and safety of the public, consistent with 10 CFR 50.34(b). Therefore, the staff concludes that the TOGS meets the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4a.4.9 Proposed Technical Specifications

In accordance with 10 CFR 50.36(a)(1), the NRC staff evaluated the sufficiency of the applicant's proposed TSs for the SHINE IUs as described in SHINE FSAR chapter 4.

The proposed TS 2.1, "Safety Limits," safety limit (SL) 2.1.1 states the following:

SL 2.1.1	The combination of differential pressure across the low temperature portion of the PSB and the wall temperature averaged through the thickness shall be within the "Acceptable" region defined by Figure 2.1.1. AND Average wall temperature for the low temperature portion of the PSB shall be ≤ 950 degrees Fahrenheit (°F) for differential pressure ≤ 95 pounds per square inch (psi).
Applicability	This safety limit applies at all times to the differential pressure and the wall temperature of the low temperature section of the PSB. The low temperature portion of the PSB includes all PSB components except the hydrogen recombiner housings, the recombiner condensers, the piping between the recombiners and the recombiner condensers, and the piping between the recombiner condensers and the TSV.

SL 2.1.1 sets differential pressure limits as a function of temperature that apply to the PSB. The limits are shown in TS Figure 2.1.1, "PSB Low Temperature Portion Safety Limit." The NRC staff determined that the material limits exceed the conditions of the material during normal operation and design basis accidents. Therefore, the staff finds SL 2.1.1 acceptable.

The proposed TS 2.1, SL 2.1.2 states the following:

SL 2.1.2	The differential pressure across the high temperature portion of the PSB shall be ≤ 115 psi and the wall temperature averaged through the thickness shall be ≤ 950°F.
Applicability	This safety limit applies at all times to the differential pressure and the wall temperature of the high temperature portion of the PSB. The high temperature portion of the PSB includes the hydrogen recombiner housings, the recombiner condensers, the piping between the recombiners and the recombiner condensers, and the piping between the recombiner condensers and the TSV.

SL 2.1.2 sets differential pressure and wall temperature limits of the high temperature portion of the PSB. The NRC staff determined that the material limits exceed the conditions of the material during normal operation and design basis accidents. Therefore, the staff finds SL 2.1.2 acceptable.

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 2.2.1	High wide range neutron flux	≤ 176% power	Modes 1 and 2
LSSS 2.2.2	High time-averaged power range neutron flux	≤ 85% power; averaged over ≤ 45 seconds	Modes 1 and 2
LSSS 2.2.3	High source range neutron flux	≤ 1.5 times the nominal flux at 95% volume of the critical fill height	Mode 1
LSSS 2.2.4	Low TOGS mainstream flow	[[PROP/ECI]]	Modes 1, 2, 3, and 4
LSSS 2.2.5	Low TOGS dump tank flow	[[PROP/ECI]]	Modes 1, 2, 3, and 4
LSSS 2.2.6	High-high TSV dump tank level	≤ 85%	Modes 1, 2, 3, and 4

LSSS 2.2.1 sets the limit on high wide range neutron flux and limits the power to less than 176 percent of the nominal operating power limit of 125 kW. The NRC staff determined that the setpoint prevents overheating of the target solution, which could lead to boiling in and pressurization of the TSV. Therefore, the staff finds LSSS 2.2.1 acceptable.

LSSS 2.2.2 sets the time-averaged power range neutron flux limit to less than or equal to 85 percent of the nominal operating power limit of 125 kW. The NRC staff determined that the setpoint prevents overheating of the target solution, which could lead to boiling in and pressurization of the TSV. The staff also determined that the setpoint prevents the buildup of hydrogen that could result in a hydrogen deflagration by keeping the hydrogen generation rate below what can be accommodated by the TOGS at the minimum flow specified in LSSS 2.2.4. Therefore, the staff finds LSSS 2.2.2 acceptable.

LSSS 2.2.3 sets a source range neutron flux limit. The NRC staff determined that this setpoint protects against a sudden increase in reactivity during the fill process, which could lead to pressurization of the TSV. Therefore, the staff finds LSSS 2.2.3 acceptable.

LSSS 2.2.4 sets the minimum flow rate for the TOGS mainstream flow. The NRC staff determined that this setpoint prevents the buildup of hydrogen that could result in a hydrogen deflagration that could exceed the PSB pressure safety limit. The setpoint is based on a hydrogen generation rate that conservatively bounds the expected hydrogen generation at the average power specified in LSSS 2.2.2. Therefore, the staff finds LSSS 2.2.4 acceptable.

LSSS 2.2.5 set the minimum flow rate for the TOGS dump tank flow. The NRC staff determined that this setpoint prevents the buildup of hydrogen that could result in a hydrogen deflagration that could exceed the PSB pressure safety limit. The minimum flow is expected to keep the hydrogen concentration below the 4 percent lower flammability limit. Therefore, the staff finds LSSS 2.2.5 acceptable.

LSSS 2.2.6 sets the high-high TSV dump tank level of 85 percent. The NRC staff determined that this setpoint ensures that the target solution height in the TSV dump tank does not obstruct the required TOGS gas flow area to provide adequate hydrogen dilution volume in the TSV dump tank. Therefore, the staff finds LSSS 2.2.6 acceptable.

The proposed TS 3.1, “Irradiation Unit Parameters,” LCO 3.1.1 states the following:

LCO 3.1.1	Both TOGS Train A and Train B shall be Operable. A TOGS train is considered Operable if: 1. The blower is Operating, and 2. The recombiner heater is Operating. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1, 2, 3, or 4, according to Table 3.1.1
Action	According to Table 3.1.1
SR 3.1.1	1. Check that both TOGS trains are Operating daily.

The proposed TS Table 3.1.1, “TOGS Actions,” states the following:

	Applicability (per IU)	**Condition and Action (per IU)**	**Completion Time**
1.	Mode 1 or 2	If TOGS Train B is not Operable, Place the associated IU in Mode 3.	Immediately
2.	Mode 1 or 2	If TOGS Train A or both trains are not Operable, Place the associated IU in Mode 3 AND Actuate an IU Cell Nitrogen Purge for the associated IU.	Immediately Immediately
3.	Mode 3 or 4	If TOGS Train B is not Operable, Place the associated IU in Mode 0	[[PROP/ECI]]
4.	Mode 3 or 4	If TOGS Train A or both trains are not Operable, Actuate an IU Cell Nitrogen Purge for the associated IU.	Immediately

LCO 3.1.1 requires both TOGS trains to be operable, provides the conditions for a TOGS train to be considered operable, and provides the actions to be taken if a TOGS train is not operable. The TOGS is designed with two recirculation trains per IU. LCO 3.1.1 requires that both the TOGS blower and the TOGS recombiner heater be operating, as defined in TS 1.3, for a single TOGS train to be considered operable. The NRC staff finds that the condition for operation would maintain hydrogen limits and iodine concentrations during startup (i.e., Mode 1),

irradiation (i.e., Mode 2), post-irradiation (shutdown) (i.e., Mode 3) and solution transfer to the RPF (i.e., Mode 4). The staff finds that if TOGS Train B is not operable in Mode 1 or 2, immediately stopping the irradiation process would limit the generation of hydrogen, and the N2PS would not need to be actuated as TOGS Train A would provide hydrogen mitigation of the TSV dump tank. The staff finds that if TOGS Train A or both trains are not operable in Mode 1 or 2, immediately stopping the irradiation process would limit the generation of hydrogen, and the N2PS would provide the hydrogen mitigation of the TSV dump tank that was lost from Train A. The staff finds that if TOGS Train B is not operable in Mode 3 or 4, removing the target solution from the TSV dump tank within the associated completion time would place the target solution in a location within the RPF where hydrogen mitigation is provided by the PVVS and not the TOGS. The staff finds that the completion time allows for the decay of short-lived fission products and that hydrogen mitigation would be provided by TOGS Train A during the completion time. The staff finds that if TOGS Train A or both trains are not operable in Mode 3 or 4, actuating the N2PS would provide the hydrogen mitigation function that was lost from Train A. Based on the above, the staff finds that LCO 3.1.1 is adequate to prevent the buildup of hydrogen to levels that could lead to a deflagration that could challenge the integrity of the PSB. Therefore, the staff finds LCO 3.1.1 acceptable.

SR 3.1.1 requires checking that both TOGS trains are operating daily. The NRC staff determined that this surveillance would ensure that TOGS is performing its intended function during Modes 1, 2, 3, and 4 and, therefore, the staff finds SR 3.1.1 acceptable.
The proposed TS 3.1, LCO 3.1.2 states the following:

LCO 3.1.2	The pressure in the TSV headspace shall be ≥ (-) 4.5 psig and ≤ (+) 0.3 psig. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1 or 2
Action	According to Table 3.1.2
SR 3.1.2	1. Verify TSV headspace pressure is within the limits daily.

The proposed TS Table 3.1.2, “TSV Headspace Pressure Actions,” states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If TSV headspace pressure is not within limits Place the associated IU in Mode 3.	1 hour

LCO 3.1.2 specifies the operating range of the pressure in the TSV headspace to be -4.5 psig to 0.3 psig and provides the actions to be taken if it is not. The NRC staff finds that the lower TSV headspace pressure limit would prevent excessive water uptake into the TOGS from increased evaporation or boiling. The staff finds that the upper TSV headspace pressure limit would prevent excessive pressure within the PSB that could result in a PSB leak or rupture. The staff finds that if the TSV headspace pressure is not within limits, placing the IU into Mode 3 would remove the target solution from the TSV and limit hydrogen generation in the IU. The staff

also finds that the TOGS would provide hydrogen mitigation during the completion time. Therefore, the staff finds LCO 3.1.2 acceptable.

SR 3.1.2 requires verification of the TSV headspace pressure limits daily. The NRC staff finds that this frequency is consistent with guidance in ANSI/ANS-15.1-2007. Therefore, the staff finds SR 3.1.2 acceptable.

The proposed TS 3.1, LCO 3.1.3 states the following:

LCO 3.1.3	Target solution volume in the TSV shall be [[PROP/ECI]]. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 2
Action	According to Table 3.1.3
SR 3.1.3	1. Verify the minimum target solution volume in the TSV daily.

The proposed TS Table 3.1.3, "TSV Volume Actions," states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If the volume of target solution in the TSV is less than the minimum volume, Place the associated IU in Mode 3.	1 hour

LCO 3.1.3 specifies a minimum target solution volume in the TSV during irradiation and provides the actions to be taken if it is not met. The minimum volume accounts for the expected holdup of water in the TOGS. The NRC staff finds that the minimum volume would maintain the peak target solution temperature below the boiling temperature. The staff finds that if the target solution volume falls below the minimum volume, transferring the target solution into the TSV dump tank would prevent boiling of the target solution. The staff also finds that the completion time would allow time to determine the reason for the low volume. The staff finds that the TRPS would respond to events where the level is lost rapidly during the completion time. Therefore, the staff finds LCO 3.1.3 acceptable.

SR 3.1.3 requires verification of the minimum target solution volume daily. The NRC staff finds that this surveillance would ensure that irradiation is not performed without the minimum target solution volume. The staff finds that this frequency is consistent with guidance in ANSI/ANS-15.1-2007. Therefore, the staff finds SR 3.1.3 acceptable.

The proposed TS 3.1, LCO 3.1.4 states the following:

LCO 3.1.4	The average temperature of the target solution within the TSV shall be ≤ 176°F as determined from the average of at least one Operable thermocouple at each TSV temperature measurement elevation. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1 or 2
Action	According to Table 3.1.4
SR 3.1.4	1. Verify TSV target solution average temperature is below the limit daily. 2. A Channel Check shall be performed on the TSV temperature indication quarterly. 3. A Channel Calibration shall be performed on the TSV temperature indication annually.

The proposed TS Table 3.1.4, "Target Solution Temperature Actions," states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If target solution average temperature is not below the limit,	
	Open at least one high voltage power supply (HVPS) breaker	Immediately
	AND	
	Place the associated IU in Mode 3.	6 hours
2.	If fewer than one thermocouple per TSV temperature measurement elevation is Operable,	
	Place the associated IU in Mode 3.	6 hours

LCO 3.1.4 specifies the maximum average target solution temperature in the TSV to be 176ºF during startup and irradiation (i.e., Modes 1 and 2) and provides the actions to be taken if it is not. The LCO also specifies that the average target solution temperature is measured using a minimum of one operable thermocouple at each temperature measurement elevation in the TSV and provides the actions to be taken if this is not the case. The LCO accounts for the expected distribution of the liquid temperature throughout the TSV. The NRC staff finds that this LCO would prevent the target solution from boiling in the TSV during operation and in the TSV dump tank after shutdown. The staff finds that if the target solution temperature is not below the limit or the required thermocouples are not operable, transferring the solution into the TSV dump tank would stop adding heat via irradiation and prevent boiling of the target solution. The staff also finds that the completion time would align with temperature trending capabilities. Therefore, the staff finds LCO 3.1.4 acceptable.

SR 3.1.4 requires verification of the TSV target solution average temperature daily and a channel check to be performed on the TSV temperature indication quarterly. The NRC staff finds that these frequencies are consistent with guidance in ANSI/ANS 15.1-2007. SR 3.1.4 also requires a channel calibration to be performed on the TSV temperature indication annually. The staff finds that this frequency is also in accordance with guidance in ANSI/ANS-15.1-2007. Therefore, the staff finds SR 3.1.4 acceptable.

The proposed TS 3.1, LCO 3.1.5 states the following:

LCO 3.1.5	Both TSV dump valves shall be Operable. TSV dump valves are considered Operable if: 1. Each TSV valve is capable of fully opening within two seconds of demand. AND 2. Each TSV dump line is capable of draining the TSV from [[PROP/ECI]] full within 183 seconds. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1 or 2
Action	According to Table 3.1.5
SR 3.1.5	1. Verify each TSV dump valve opens in ≤ 2 seconds of demand quarterly. 2. Verify the drain time of each TSV dump line is ≤ 183 seconds starting when the TSV is ≥ [[PROP/ECI]] full quarterly.

The proposed TS Table 3.1.5, “TSV Dump Valve Actions,” states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If one or more TSV dump valve(s) are not Operable, Place the associated IU in Mode 3.	1 hour

LCO 3.1.5 requires both TSV dump valves to be operable, provides conditions for the TSV dump valves to be considered operable, and provides the actions to be taken if they are not. The NRC staff finds that this condition would ensure that the target solution is able to drain from the TSV to the TSV dump tank within the time assumed in the accident analysis and that the drain rate allows for the failure of one dump valve. The staff finds that if the dump valves are not operable, the valves fail to the open position and the target solution would be transferred to the TSV dump tank. The staff also finds that the completion time would allow time to repair minor problems. Therefore, the staff finds LCO 3.1.5 acceptable.

SR 3.1.5 requires verification of the opening time of each TSV dump valve and the drain time of each TSV dump line quarterly. The NRC staff notes that while the guidance in ANSI/ANS-15.1-2007 does not discuss valve opening times and dump line drain times, surveillance requirement guidance for similar systems of a research reactor can be applied. The staff finds that these frequencies are consistent with guidance in ANSI/ANS 15.1-2007. Therefore, the staff finds SR 3.1.5 acceptable.

The proposed TS 3.1, LCO 3.1.6 states the following:

LCO 3.1.6	Temperature and average power density of the target solution in the TSV shall be within the “Acceptable” region of Figure 3.1.6, defined by the following equation: Power Density Limit (kW/L) = [[PROP/ECI]] Note – This LCO does not apply during driver restart transients;see LCO 3.1.7 for the transient average power density limit. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 2
Action	According to Table 3.1.6
SR 3.1.6	1. Verify temperature and average power density of the target solution in the TSV is within the “Acceptable” region of Figure 3.1.6 hourly during power ramp up [[PROP/ECI]].

The proposed TS Table 3.1.6, “Average Power Density Limit Actions,” states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If the average power density-temperature conditions are not within the acceptable region for ≥ 1 second, Place the associated IU in Mode 3.	Immediately

LCO 3.1.6 specifies the average power density limit as a function of temperature and provides the actions to be taken if it is not in the acceptable region. The NRC staff finds that this condition would prevent the precipitation of uranyl peroxide in the target solution undergoing irradiation. The limit has an approximately 30 percent margin to the precipitation limit observed in historical operating data. The staff finds that if the conditions are not within the acceptable region, immediately transferring the target solution to the TSV dump tank would stop adding heat and power via irradiation. Therefore, the staff finds LCO 3.1.6 acceptable.

SR 3.1.6 requires verification, during power ramp up, of the temperature and average power density of the target solution hourly. The NRC staff finds that this surveillance would ensure that the temperature and average power density are maintained within the limits during ramp up to full power. Therefore, the staff finds SR 3.1.6 acceptable.

The proposed TS 3.1, LCO 3.1.7 states the following:

LCO 3.1.7	Transient average power density of target solution within the TSV shall be [[PROP/ECI]]. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 2
Action	According to Table 3.1.7
SR 3.1.7	1. Verify transient average power density of the target solution in the TSV did not exceed [[PROP/ECI]] during any driver restart transient after a loss of driver event.

The proposed TS Table 3.1.7, "Transient Average Power Density Actions," states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If the transient average power density limit is exceeded, Place the associated IU in Mode 3.	Immediately

LCO 3.1.7 specifies the average power density limit of the target solution during transients and provides the actions to take if it is not in the acceptable range. The NRC staff finds that the condition for operation would limit temperature, pressure, and hydrogen generation during transient events. The staff also finds that the precipitation of uranyl peroxide is not a concern in these instances since there is not enough time for peroxide concentrations to reach steady state. The staff finds that if the limit is exceeded, immediately transferring the target solution to the TSV dump tank would limit hydrogen generation, temperature increases, and pressure increases. Therefore, the staff finds LCO 3.1.7 acceptable.

SR 3.1.7 requires verification of the transient average power density during any driver restart transient after a loss of driver event. The NRC staff finds that the surveillance would ensure that the transient average power density was maintained within analyzed limits during the restart. The staff also finds that power excursions would result in control room alarms to alert the operator. Therefore, the staff finds SR 3.1.7 acceptable.

The proposed TS 3.1, LCO 3.1.8 states the following:

LCO 3.1.8	Target solution shall be held in the TSV dump tank for ≥ the required minimum hold time specified in Table 3.1.8 if the target solution batch has been irradiated at > 1 effective full power minute during the immediately preceding irradiation cycle.
Applicability	Associated IU in Mode 4
SR 3.1.8	1. Verify the minimum hold time requirement of Table 3.1.8 has been achieved prior to transfer of target solution from the TSV dump tank.

The proposed TS Table 3.1.8, “Required Minimum Hold Time,” states the following:

Maximum Historical Irradiation Power	Required Minimum Hold Time
> 0 kW but ≤ 10 kW	[[PROP/ECI]]
> 10 kW but ≤ 70 kW	[[PROP/ECI]]
> 70 kW	[[PROP/ECI]]

LCO 3.1.8 specifies the target solution minimum hold time in the TSV dump tank before being transferred to the RPF based on the maximum historical irradiation power level. The NRC staff finds that this condition for operation would limit the radionuclide inventory of isotopes with short half-lives and ensure that the source term does not exceed the conditions assumed in the accident analysis. Therefore, the staff finds LCO 3.1.8 acceptable.

SR 3.1.8 requires verification of the hold time before the target solution is transferred from the TSV dump tank to the RPF. The NRC staff finds that this surveillance would ensure that target solution is not transferred before the minimum hold time. Therefore, the staff finds SR 3.1.8 acceptable.

The proposed TS 3.3, “Coolant Systems,” LCO 3.3.1 states the following:

LCO 3.3.1	The light water pool water level shall be ≥ 14 feet, relative to the bottom of the pool. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1, 2, 3, or 4, according to Table 3.3.1
Action	According to Table 3.3.1
SR 3.3.1	1. The light water pool water level shall be verified to be above the minimum specified level daily and prior to entering Mode 1.

The proposed TS Table 3.3.1, “Light Water Pool Level Actions,” states the following:

	Applicability (per IU)	Action (per IU)	Completion Time
1.	Mode 1 or 2	If the light water pool is less than the minimum level, Place the associated IU in Mode 3 AND Place the associated IU in Mode 0.	6 hours [[PROP/ECI]]
2.	Mode 3 or 4	If the light water pool is less than the minimum level, Place the associated IU in Mode 0.	[[PROP/ECI]]

LCO 3.3.1 specifies the minimum light water pool level relative to the bottom of the pool and the actions to be taken if the level is not met. The NRC staff finds that the minimum light water pool level would provide adequate biological shielding and cooling. The staff finds that if the light water pool level is less than the minimum limit, transferring the target solution from the TSV to the TSV dump tank would limit the radiation levels and temperature of the metal components and the biological shield. The staff also finds that a rapid loss of light water pool level is not expected. Therefore, the staff finds LCO 3.3.1 acceptable.

SR 3.3.1 requires verification of the light water pool level daily and before entering Mode 1. The NRC staff finds that this surveillance would ensure that the light water pool level is above the applicable limit daily and prior to entering Mode 1 operations. Therefore, the staff finds SR 3.3.1 acceptable.

The proposed TS 3.8, “Facility-Specific,” LCO 3.8.2 states the following:

LCO 3.8.2	The concentration of uranium in the target solution in the TSV shall be [[PROP/ECI]].
Applicability	Target solution in the associated TSV
SR 3.8.2	1. After preparing a new batch of target solution, the target solution uranium concentration shall be verified to be below the uranium concentration limit prior to transferring the batch to a TSV in Mode 1 2. After adding uranyl sulfate makeup solution to an existing batch, the target solution uranium concentration shall be verified to be below the uranium concentration limit prior to transferring the batch to a TSV in Mode 1

LCO 3.8.2 specifies the target solution uranium concentration limit. The NRC staff finds that the condition for operation would ensure that the target solution remains subcritical in an inadvertent fill scenario. Since the concentration limit is less than the concentration of maximum reactivity, the staff finds that the limit would also prevent boiling of the target solution. Therefore, the staff finds LCO 3.8.2 acceptable.

SR 3.8.2 requires verification of the target solution uranium concentration before entering Mode 1 for both a new batch and after adding uranyl sulfate makeup solution to an existing batch. The NRC staff finds that the surveillance would prevent target solution with uranium concentration above the limit from being transferred to the TSV in Mode 1. The staff also finds that uranium concentration would not change during irradiation. Therefore, the staff finds SR 3.8.2 acceptable.

The proposed TS 3.8, LCO 3.8.3 states the following:

LCO 3.8.3	[[PROP/ECI]] and pH of the target solution shall be within the "Acceptable" region of Figure 3.8.3, defined by the following equation: [[PROP/ECI]]
Applicability	Target solution in the associated TSV
SR 3.8.3	1. After preparing a new batch of target solution, the [[PROP/ECI]] and pH shall be verified to be within the "Acceptable" region of Figure 3.8.3 prior to transferring the batch to a TSV in Mode 1 2. After adding uranyl sulfate makeup solution to an existing batch, the [[PROP/ECI]] and pH shall be verified to be within the "Acceptable" region of Figure 3.8.3 prior to transferring the batch to a TSV in Mode 1

LCO 3.8.3 specifies the acceptable region of the target solution catalyst concentration and pH based on the defining equation. The NRC staff finds that the condition for operation would prevent uranyl peroxide precipitation in the target solution. Therefore, the staff finds LCO 3.8.3 acceptable.

SR 3.8.3 requires verification of the target solution catalyst concentration and pH after both preparing a new batch and adding uranyl sulfate makeup solution to an existing batch. The NRC staff finds that the surveillance would prevent target solution with target solution catalyst concentration and pH outside the acceptable region from being transferred to the TSV in Mode 1. The staff also finds that target solution catalyst concentration and pH would not change during irradiation. Therefore, the staff finds SR 3.8.3 acceptable.

The proposed TS 3.8, LCO 3.8.6 states the following:

LCO 3.8.6	The beam off pressure in the target chamber shall be [[PROP/ECI]]. Note – This LCO is applied to each IU independently; actions are only applicable to the IU(s) that fail to meet the LCO.
Applicability	Associated IU in Mode 1, 2, 3 or 4
Action	According to Table 3.8.6
SR 3.8.6	1. Verify the tritium pressure in each NDAS target chamber is below the limit daily.

The proposed TS Table 3.8.6, "Target Chamber Pressure Actions," states the following:

	Condition and Action (per IU)	**Completion Time**
1.	If the target chamber pressure is above the allowable limit,	
	Open at least one HVPS breaker	1 hour
	AND	
	Evacuate tritium from the NDAS target chamber until pressure is below the limit.	12 hours

LCO 3.8.6 specifies the beam off pressure in the NDAS target chamber limit and the actions to be taken if it is not within the limit. The NRC staff finds that the condition for operation would ensure that the amount of tritium in an IU cell is below the limit described in the accident analysis and limits the tritium source term. The staff finds that if the NDAS target chamber pressure is above the limit, opening at least one HVPS breaker would shut down the neutron driver. The staff also finds that opening at least one HVPS breaker within one hour would minimize the probability of a release exceeding that assumed in the accident analysis. The staff finds that evacuating tritium from the NDAS target chamber until pressure is below the limit within 12 hours would also minimize the probability of a release. Therefore, the staff finds LCO 3.8.6 acceptable.

SR 3.8.6 requires verification of the tritium pressure in each NDAS target chamber daily. The NRC staff finds that the surveillance would ensure that the pressure limit is not exceeded during irradiation. The staff also finds that PICS monitors the pressure in the NDAS target chamber. Therefore, the staff finds SR 3.8.6 acceptable.

The proposed TS 4.1, “Site and Facility Description,” DF 4.1.3 states the following:

DF 4.1.3	1. The PVVS carbon delay bed minimum efficiency for iodine is 99%. 2. The PVVS carbon delay bed delay time is 40 days, based on the travel time of xenon and the depth of the bed. 3. The TOGS zeolite bed minimum efficiency for iodine is 95%. 4. The TOGS recombiner minimum efficiency for hydrogen recombination is 95% for hydrogen concentrations above 3% by volume when heated to ≥ 212°F. 5. The supercell RVZ1 outlet carbon filter minimum efficiency for iodine is 99%.

DF 4.1.3 states the PVVS carbon delay bed minimum efficiency and delay time. The NRC staff finds that the carbon delay bed minimum efficiency for iodine would capture the iodine and maintain iodine concentrations within acceptable levels. The staff also finds that the carbon delay bed delay time would delay airborne radioactive sources to acceptable levels prior to release to the environment. DF 4.1.3 also states the TOGS minimum efficiency for the zeolite bed and the recombiner. The staff finds that the hydrogen recombiners minimum efficiency would prevent the hydrogen concentration from reaching a level at which deflagration or detonation could occur. The staff also finds that the zeolite bed minimum efficiency would remove iodine from the sweep gas and maintain iodine concentrations within acceptable levels. This limits the amount of iodine that could be released in the event of a breach of the TOGS pressure boundary. DF 4.1.3 states the RVZ1 outlet carbon filter minimum efficiency. The staff finds that the RVZ1 outlet carbon filter minimum efficiency for iodine would capture iodine and maintain iodine concentrations within acceptable levels. Therefore, the staff finds DF 4.1.3 acceptable.

The proposed TS 4.3, “Subcritical Assembly System and Target Solution,” DF 4.3.1 states the following:

DF 4.3.1	Target solution is an aqueous uranyl sulfate solution containing uranium enriched to less than 20 wt. % in U-235.

DF 4.3.1 states that the target solution is an aqueous uranyl sulfate solution containing uranium enriched to less than 20 percent by weight in U-235. SHINE FSAR section 4a2.2.1.12 states that the target solution is a uranyl sulfate solution with an enrichment of 19.75 +/- 0.2 percent. The NRC staff finds that the target solution design information is sufficiently supported in the FSAR with adequate functional descriptions, tables, text, and referenced reports. The design limits of the target solution are clearly described such that the safety related implications of these limits, and their relationship to the rest of facility, is also described. Therefore, the staff finds DF 4.3.1 acceptable.

The proposed TS 4.3, DF 4.3.2 states the following:

DF 4.3.2	1. The subcritical assembly system principally consists of the TSV, subcritical assembly support structure (SASS), neutron multiplier and TSV dump tank, and is described in FSAR Section 4a2.2. 2. Redundant overflow tubes are provided for the TSV to protect the TSV headspace to allow for TOGS operation.

DF 4.3.2 states the components of the SCAS and that the TSV headspace is protected by redundant overflow tubes in the TSV. The NRC staff finds that the SCAS components are sufficiently described in SHINE FSAR section 4a2.2. The staff finds that the TSV can be emptied into criticality-safe geometry TSV dump tanks via the TSV dump valves, and that the valves can be opened by the TRPS and fail to the safe open position. The staff also finds that there are redundant flow paths to meet single failure criteria. Therefore, the staff finds DF 4.3.2 acceptable.

4a.5 Review Findings

The NRC staff reviewed the descriptions and discussions of SHINE’s IF, as described in SHINE FSAR section 4a2, 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 design of the IF 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, “Domestic Licensing of Production and Utilization Facilities,” 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 IF are sufficient and meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.

4b Radioisotope Production Facility

SER section 4b, “Radioisotope Production Facility,” provides an evaluation of the final design of SHINE’s RPF as presented in SHINE FSAR section 4b, “Radioisotope Production Facility Description.”

The facility description addresses the principal features, operating characteristics, and parameters of the RPF. The primary functions of the RPF are to recover, purify, and package Mo-99.

4b.1 Areas of Review

The NRC staff reviewed SHINE FSAR section 4b against applicable regulatory requirements, using appropriate regulatory guidance and acceptance criteria, to assess the sufficiency of the final design and performance of the SHINE RPF. As part of this review, the staff evaluated descriptions and discussions of the SHINE RPF, with special attention to the principal safety considerations that were factored into the design and operation of the RPF. The final design bases of the SHINE RPF were evaluated to ensure that the design bases and functions of the SSCs are presented in sufficient detail to allow a clear understanding of the facility and to ensure that the facility can be operated for its intended purpose and within regulatory limits for ensuring the health and safety of the operating staff and the public. Drawings and diagrams were evaluated to determine if they present a clear and general understanding of the physical facility features and of the processes involved.

Areas of review for this section include the RPF facility and process description, the RPF biological shield, the radioisotope extraction system, and special nuclear material (SNM) processing and storage.

4b.2 Summary of Application

The SHINE FSAR includes information that describes the RPF, presents the design bases and the limits on its operation, and presents a safety analysis of the SSCs of the facility. The SHINE RPF includes the target solution preparation system (TSPS); the Mo-99 extraction and purification system (MEPS); iodine and xenon purification and packaging (IXP); target solution staging system (TSSS); uranium receipt and storage system; process vessel vent system (PVVS); radioactive liquid waste storage (RLWS); radioactive liquid waste immobilization (RLWI); VTS; and molybdenum isotope product packaging system.

4b.3 Regulatory Requirements and Guidance and Acceptance Criteria

The NRC staff reviewed SHINE FSAR chapter 4 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.

4b.3.1 Applicable Regulatory Requirements

The applicable regulatory requirements for the evaluation of the SHINE RPF are as follows:

- 10 CFR 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”

4b.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 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 RGs, IEEE standards, 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 of this SER.

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

The NRC staff performed a review of the technical information presented in SHINE FSAR section 4b, as supplemented, to assess the sufficiency of the final design and performance of SHINE's RPF for the issuance of an operating license. The sufficiency of the final design and performance of SHINE's RPF is determined by ensuring that it meets applicable regulatory requirements, guidance, and acceptance criteria, as discussed in section 4b.3, "Regulatory Requirements and Guidance and Acceptance Criteria," of this SER. The findings of the staff review are described in Section 4b.5, "Review Findings," of this SER.

4b.4.1 Facility and Process Description

The NRC staff evaluated the sufficiency of SHINE's facility and process description of the RPF, as presented in SHINE FSAR section 4b.1, "Facility and Process Description," using the guidance and acceptance criteria from section 4b.1, "Facility and Process Description," of the ISG augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of section 4b.1 of the ISG augmenting NUREG-1537, Part 2, the information submitted in SHINE FSAR section 4b.1 is descriptive in nature and requires no technical analysis. The information in this section serves as background for more detailed descriptions in later sections of the application. However, the NRC staff considered whether the information presented in this section is consistent with that in other sections of the FSAR.

SHINE FSAR section 4b.1 contains a summary description of the RPF. It includes the principal safety considerations that were factored into the RPF design, construction, and operation. The design bases and functions of the SSCs are presented in sufficient detail to allow a clear understanding and for the NRC staff to assess that the RPF can be operated for its intended purpose and within regulatory limits for ensuring the health and safety of the workers and the public. Drawings and diagrams are provided to allow a clear and general understanding of the physical RPF features and of the processes involved. The primary functions of the RPF are to extract, purify, package, and ship medical radioisotopes. The primary fission product barrier in the RPF consists of vessels and associated piping, which contain the irradiated SNM and fission products (in solid, liquid, or gaseous form) during the separation process.

SHINE FSAR section 4b.1 provides a summary of the maximum amount of SNM and the physical and chemical forms of SNM used in the RPF processes.

SHINE FSAR section 4b.1 contains a summary description of the raw materials, byproducts, wastes, and finished products of the RPF. This information includes data on expected levels of trace impurities or contaminants in the final product (particularly fission products or transuranic elements) characterized by identity and concentration.

SHINE FSAR section 4b.1 contains a general description of the design basis and implementation of any criticality safety features of the RPF for establishing and maintaining a nuclear criticality safety program. The NRC staff evaluation of the criticality safety program is discussed in section 6b.4.3, "Nuclear Criticality Safety," of this SER.

SHINE FSAR section 4b.1 contains a description of the radiological protection features designed to prevent the release of radioactive material and used to maintain radiation levels below applicable radiation exposure limits. The NRC staff evaluation of the engineered safety features that will provide radiological protection to workers and the environment in accident scenarios is discussed in chapter 13.0, “Accident Analysis,” of this SER.

SHINE FSAR section 4b.1 contains a description of the design basis and method for implementation of any hazardous chemical safety features of the RPF and for establishing and maintaining a hazardous chemical safety program. The NRC staff evaluation of the chemical safety program is discussed in section 13b.4.3, “Analyses of Accidents with Hazardous Chemicals,” of this SER.

Based on the information presented in SHINE FSAR section 4b.1, the NRC staff finds that the summary description of the facility and processes of the SHINE RPF meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4b.4.2 Radioisotope Production Facility Biological Shield

The NRC staff evaluated the sufficiency of the SHINE RPF biological shield, as presented in SHINE FSAR section 4b.2, “Radioisotope Production Facility Biological Shield,” using the guidance and acceptance criteria from section 4.4, “Biological Shield,” of NUREG-1537, Parts 1 and 2, and section 4b.2, “Processing Facility Biological Shield,’’ of the ISG augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of section 4.4 of NUREG-1537, Part 2, the NRC staff considered whether the objectives of the biological shield design bases are sufficient to protect the health and safety of the public and facility staff.

SHINE FSAR section 4b.2.1 states that the production facility biological shield (PFBS) provides a barrier to protect SHINE facility personnel, members of the public, and various components and equipment of the SHINE facility by reducing radiation exposure. The RPF receives irradiated target solution from an IU cell and distributes the target solution to various downstream processes. The target solution has a fission product activity (source locations and source term characterizations) that is defined in SHINE FSAR chapter 11. The major systems and areas outside of the IU cell that the target solution and by-product material occupy are as follows: supercell (consisting of the cells containing the extraction, purification, and packaging system; the cells containing the PVVS; and the cells containing the IXP); process tank vaults; process valve pits; pipe trenches; carbon delay bed vault; solid waste drum storage bore holes; and the RLWI shielded enclosure.

In relation to the function of the PFBS, the minimization of dose to workers and the public during normal operation and design basis accidents, the SHINE FSAR references and describes the ventilation function of the RVZ1e. The RVZ1e function in relation to worker and public dose during normal and emergency operations is presented in SHINE FSAR section 9a2.1.1.2. The FSAR description includes a summary of the design basis of all RVZ1e components and functions that are engineered to control the release of radioactive contaminants to the environment under normal and emergency operating conditions.

The safety function of RVZ1e is to control the spread of contamination, and it services several portions of the PFBS: the target solution preparation tank, dissolution tank, and preparation system glovebox; the supercell; the uranium receipt and storage system glovebox; and the RLWI shield. RVZ1e is engineered to exhaust air from high contamination areas (through an exhaust stack) and to maintain negative pressure inside the confinement. The SHINE FSAR describes the RVZ1e processes with a supporting figure that illustrates (through a flow diagram) the portions of the PFBS that RVZ1e services. The PFBS also has a confinement function to support the following engineered safety features: supercell confinement; below grade confinement; and PVVS isolation.

SHINE FSAR section 4b.2.2, “Biological Shield Design Basis,” describes the PFBS design, including a detailed description of the dimensions of the PFBS, the materials from which it is constructed, the applicable engineering standards to which it is designed, the shield materials, and the functional requirements of each shielding segment.

For the selected materials, SHINE listed the design bases and applicable engineering standards to which they were selected, which are RG 1.69 and ACI 349-13. SHINE stated that the purpose of the shielding materials is to reduce dose during normal operation, consistent with ALARA objectives and the dose limits in 10 CFR Part 20, and to mitigate exposure during accidents as described in SHINE FSAR chapter 13.

For the PFBS design and geometry, SHINE FSAR section 4b.2.2.2 presents the general shapes of the shielding segments for each functional portion of the RPF. The FSAR describes the range of thicknesses of the shielding segments, the lead and concrete from which the segments were constructed, and the dimensions and materials of the matching cover plugs for the accessible portions of the PFBS. The geometry and dimensions are adequately supported in the FSAR by the referenced figures. The figures also note which portions of the RPF are above ground and which are below ground.

SHINE indicated that the shield thicknesses were engineered to support ALARA principals and to keep calculated doses within the 10 CFR Part 20 limits. For portions of the PFBS with higher doses, such as the interfaces between shielding segments, SHINE FSAR section 11.1 discusses a radiation protection program that will be put in place to monitor doses in these known locations.

SHINE FSAR section 4b.2.2.2.1 describes the functional basis of the PFBS. The functions and compensations of the shielding system are engineered to meet ALARA objectives with the thicknesses of the slabs, the use of below grade solution transfers (between the PFBS and the irradiation cell biological shield (ICBS)), supplemental shielding, access plugs for removable segments, engineered features to break up the streaming path at interfaces, shielded gates in combination with compensated shielding, and leaded observation windows for the hot cells within the supercell of the RPF.

SHINE FSAR section 4b.2.2.2.1, “Functional Design of Biological Shield,” and section 4b.2.3.3, “Radiation Streaming,” describe the efforts put in place to meet ALARA during routine operations and inspections, and these descriptions are adequately supported by the supplied figures. The engineered shielding features for the waste drum, pipe trench, tank vault, carbon delay bed, RLWI, and the supercell are adequately presented, along with the matching configuration changes (access plug removals, compensating gates, door gates for drum removal and material transfers, and supplemental shielding at manipulator penetrations). The shield design also describes the entry and exit facilities for products, wastes, process equipment, and operating staff. Transitions between PBFS and ICBS are adequately described and supported in the FSAR.

SHINE FSAR section 4b.2.3 addresses the selected materials and their justification, the radiation damage calculations and criteria for acceptance, the dose and damage to the other materials, and radiation streaming. Materials that are customarily used for shielding were employed for all portions of the PBFS (steel, lead, lead glass, and standard-density concrete with reinforcing steel). For those portions of the PBFS with high activity and potential dose, lead was used.

SHINE performed radiation damage calculations with MCNP to approximate the flux and integrated fluence throughout the PFBS. The geometry of the PFBS was explicitly modeled with enough direct representations of neutrons and gammas to calculate statistically meaningful results, with variance reduction techniques in hard-to-converge areas. Neutron and gamma transport from the fresh and irradiated target solution and the interactions with the shielding materials were simulated. The MCNP models were developed with conservative assumptions.

This analysis was done for all portions of the post-irradiated target solution, fresh target solution within the staging system, the MEPS, and the IXP. To address radiation streaming, particularly at the interfaces of dissimilar materials, at gaps between segments, at segments of shielding that are engineered to be thinner than nominal, and at penetrations, SHINE employed non-linear paths and supplemental shielding to reduce dose. SHINE explicitly modeled tolerance gaps to accurately calculate dose and to correct with supplemental shielding.

For its overall shielding methodology, SHINE determined the thickness conservatively to control dose and structural integrity. RG 1.69 references ANSI/ANS 6.4-2006, “Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants,” as an acceptable basis for shielding calculations. SHINE used this standard as guidance during the development of its MCNP models to determine the neutron and gamma-ray dose rates behind shielding thicknesses and to determine the amount of flux that a shielding material can receive and still maintain structural integrity. SHINE used this standard to define the acceptable criteria with respect to flux and temperature. With MCNP calculations throughout the PFBS, SHINE demonstrated that these criteria are met and that the nuclear heating can be neglected. SHINE also calculated the cumulative 30-year lifetime gamma dose (2E+9 rad) to the shielding concrete to demonstrate that the concrete will not suffer from degradation consistent with the results of the studies documented in NUREG/CR-7171. SHINE also used MCNP to determine that fluxes within the steel, lead, and lead glass do not lead to the degradation of these materials and to demonstrate that groundwater and soils are not activated.

For structural integrity of concrete shielding, SHINE references ACI 349-13 as the appropriate standard, whereas RG 1.69 references ACI 349-06. ACI 349-13 superseded ACI 349-06 and was published after the publication of RG 1.69. ACI 349-13 was also developed for nuclear safety related concrete. Both ACI 349-13 and ACI 349-06 were developed based upon the strength design method, with acceptable compressive, tensile, and shear loadings determined by a calculated temperature criterion of 150ºF (66ºC) within the concrete; SHINE’s calculated concrete temperature was below this limit. The SHINE FSAR also takes the same exceptions to ACI 349-13 as are taken by RG 1.69 with respect to ACI 349-06.

SHINE developed proposed TSs that are appropriate for defining operating limits that establish the integrity of the PFBS such that it can fulfill its safety function and control dose to workers and the public during normal operation and accidents. The proposed TSs define limiting conditions of operation and surveillances with respect to the operability of: the supercell confinement damper; RVZ1e outlet isolation valves for confinement; PVVS tank flowrates; and radiation monitors in the supercell for the RVZ1e exhaust lines (PVVS hot cell; extraction and IXP hot cells; and purification and packaging hot cells).

The NRC staff finds that all of the essential physical and operational features of the biological shield that are required to prevent the release of radioactive material and to maintain radiation levels below the 10 CFR Part 20 limits for the protection of workers and the public are identified in SHINE FSAR section 4b.2.

Based on the information presented in SHINE FSAR section 4b.2, the NRC staff finds that the technical analysis, applicable standards, and relevant criteria offer reasonable assurance that the PFBS will control exposure to radiation within the 10 CFR Part 20 limits and the guidelines of the facility ALARA program, and that the biological shield will control radiation-induced degradation to the components of the RPF. Therefore, the staff finds that the description of the biological shield meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4b.4.3 Radioisotope Extraction System

The NRC staff evaluated the sufficiency of the SHINE RPF radioisotope extraction system, as presented in SHINE FSAR section 4b.3, “Radioisotope Extraction System,” using the guidance and acceptance criteria from Section 4b.3, “Radioisotope Extraction System,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of section 4b.3 of the ISG augmenting NUREG-1537, Part 2, the NRC staff considered whether the information provided a clear understanding of the processes and is consistent with the information in other sections of the FSAR.

SHINE FSAR section 4b.3 provides the design, detailed description, and the following processing details of the MEPS:

- Process description, including process functions; safety functions; primary system interfaces; the process sequence, including molybdenum extraction and concentration and purification process sequences; and process equipment.

- Physical, chemical, and radioisotope properties of the target solution, including volumes in process and radioactive inventory in process.

- Criticality control features of the systems that are provided through use of favorable geometry equipment.

- Shielding and radiological protection features of the MEPS.

The MEPS processes are performed in shielded hot cells, which keeps worker exposure to radiation within the regulatory limits of 10 CFR Part 20. The processes are remotely and manually controlled, and performed with tele-manipulators, with minimal automated sequences. Radiation monitors and alarms are used to monitor release of radiological materials, monitor high background gamma dose levels, and detect criticality events. Piping that contains potentially radiological material is routed through shielded pipe chases to limit worker exposure to radiation. Tanks within the MEPS are inside shielded hot cells, so additional tank shielding is not required.

On the basis of its review, the NRC staff determined that the MEPS process descriptions in SHINE FSAR section 4b.3 provide a detailed account of the SNM in process, along with any included fission-product radioactivity. The description of the post-irradiation processing after the target solution is removed from the IF gives a clear understanding that these operations can be conducted safely in the RPF. The MEPS processing facilities and apparatus are described in sufficient detail to provide confidence that the SNM and byproduct material can be controlled throughout the process so that the health and safety of the public will be protected.

Based on the information presented in SHINE FSAR section 4b.3, the NRC staff finds that the description of the SHINE RPF radioisotope extraction system meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4b.4.4 Special Nuclear Material Processing and Storage

SHINE FSAR section 4b.4, "Special Nuclear Material Processing and Storage," describes the processing components and procedures involved in handling, processing, and storing SNM in the SHINE RPF. The processing and storage of SNM is conducted in the SHINE facility building and the waste staging and shipping building. SNM is used throughout the radiologically controlled area in both unirradiated and irradiated forms for the production of medical radioisotopes. Mo-99 is extracted from the irradiated SNM in the MEPS as described in SHINE FSAR section 4b.3. Following Mo-99 extraction, the target solution is directed to one of the target solution hold tanks, the target solution storage tanks, or the RLWS system. In the target solution hold tanks, sampling and adjustments to chemistry are performed as required. Target solution is stored in favorable geometry tanks designed to keep the target solution subcritical.

4b.4.4.1 Processing of Irradiated Special Nuclear Material

The NRC staff evaluated the sufficiency of the SHINE RPF irradiated SNM processing and storage, as presented in SHINE FSAR section 4b.4.1, "Processing of Irradiated Special Nuclear Material," using the guidance and acceptance criteria from section 4b.4.1, "Processing of Irradiated Special Nuclear Material," of the ISG augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of section 4b.4.1 of the ISG augmenting NUREG-1537, Part 2, the NRC staff considered whether the information provided a clear understanding of the processes and is consistent with the information in other sections of the FSAR.

SHINE FSAR table 4b.4-1 specifies the chemical form, physical form, and approximate maximum inventory in pounds and kilograms of the SNM in the SHINE facility. SHINE FSAR section 4b.4.1, along with figure 4b.4-1, presents a clear description of the process systems and components to provide an understanding that the facility can be operated safely within regulatory limits. The processing components are compatible with the process material that they contain so as to withstand the effects of corrosion and radiation. The processing system is designed to manage fission-product and radiolysis gases that evolve in the process.

SHINE FSAR section 4b.4.1.2 describes the physical properties of the system. This includes process fluid properties, physical and chemical properties, radioisotope properties, and hazardous chemicals. Additionally, SHINE FSAR section 4b.4.1.2.4 states that for solution adjustments in the TSSS, adjustments may include uranyl sulfate and sulfuric acid additions, which are hazardous chemicals. Chemicals are prepared within well-ventilated areas and within enclosures as needed to prevent exposure. Off-gases evolved within the TSSS are isolated from workers and ventilated by the PVVS, as described in SHINE FSAR section 9b.6. Uranyl sulfate is prepared in the TSPS, as described in SHINE FSAR section 4b.4.2.2. SHINE has chemical inventory controls, including separation of chemicals, based on the potential for exothermic reactions. SHINE FSAR table 4b.4-4 provides the approximate TSPS hazardous chemical inventory.

SHINE FSAR section 4.b.4.1.2.5 states that the SNM within the irradiated target solution in the RPF are LEU and small amounts of plutonium. The LEU is in the form of uranyl sulfate, and the plutonium is in aqueous form in the target solution. The TSSS contains up to eight batches of target solution in the target solution hold tanks and up to two batches in the target solution storage tanks. SHINE FSAR table 4a2.2-1 provides the uranium inventory in a target solution batch. SHINE FSAR table 4a2.6-2 provides the plutonium inventory in a target solution batch. SHINE FSAR section 4b.1 provides the maximum SNM inventory within each RPF process system.

SHINE FSAR section 4b.4.1.3, “Criticality Control Features,” states that the TSSS criticality safety controls are discussed in detail in SHINE FSAR section 6b.3.2.1.

SHINE FSAR section 4.b.4.1.4, “Shielding and Radiological Protection,” states that storage and adjustment of the target solution is performed in the TSSS within the shielded tank vaults of the PFBS. Piping that contains potentially radioactive material is transferred through shielded pipe trenches to limit the exposure of individuals to radiation. Radiation monitors and alarms are used to detect the release of radiological materials, detect high background gamma dose levels, and detect criticality were it to occur, as described in SHINE FSAR section 7.7.

On the basis of its review, the NRC staff determined that the process descriptions in SHINE FSAR section 4b.4.1, including tables and figures, provide a detailed account of the irradiated SNM in process, along with any included fission-product radioactivity. The staff finds that the process descriptions for the TSSS processes are sufficient to provide a clear understanding that these operations can be conducted safely in the RPF. The staff determined that the TSSS processing facilities and apparatuses are described in sufficient detail to provide confidence that the irradiated SNM and byproduct material can be controlled throughout the process so that the health and safety of the public will be protected.

Based on the information presented in SHINE FSAR section 4b.4.1, the NRC staff finds that the description of the SHINE RPF irradiated SNM processing and storage meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4b.4.4.2 Processing of Unirradiated Special Nuclear Material

The NRC staff evaluated the sufficiency of the SHINE RPF unirradiated SNM processing and storage, as presented in SHINE FSAR section 4b.4.2, “Processing of Unirradiated Special Nuclear Material,” using the guidance and acceptance criteria from section 4b.4.2, “Processing of Unirradiated Special Nuclear Material,” of the ISG augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of section 4b.4.2 of the ISG augmenting NUREG-1537, Part 2, the NRC staff considered whether the information provided a clear understanding of the processes and is consistent with the information in other sections of the FSAR.

SHINE FSAR section 4b.4.2 states that shipments of uranium received by the SHINE facility consist of LEU and that the nominal enrichment of the received uranium is 19.75 +/- 0.2 percent. The SNM is transported in approved shipping containers and is stored in those containers in accordance with packaging limitations for use. The shipping containers are manually transferred to where the SNM may be removed from the shipping containers. Each package of SNM is inspected upon receipt. Dependent on the form received, the SNM is repackaged from the shipping containers to either uranium metal storage canisters or uranium oxide storage canisters and placed in a favorable configuration on the uranium metal storage rack or uranium oxide storage rack for criticality safety. The uranium metal is converted to uranium oxide by a furnace within the uranium receipt and storage system glovebox. The uranium oxide produced from the oxidation of unirradiated uranium metal is stored in uranium oxide storage canisters in favorable configuration for criticality safety on the uranium oxide storage rack. Uranium oxide is stored for future production of uranyl sulfate target solution.

SHINE FSAR sections 4b.4.2.2 through 4b.4.2.5 describe the operations involving SNM before it is used as target solution in the IF. The process descriptions include detailed procedures used in each operation, including a description of the quantity, physical and chemical form of the SNM involved in each operation, and enough detail to enable the development and analysis of potential accident sequences in SHINE FSAR chapter 13.

All the essential physical and operational features of the unirradiated SNM processing system that are required to prevent the release of radioactive material and to maintain radiation levels below applicable radiation exposure limits in 10 CFR Part 20, for the protection of workers and the public, are identified and included in the proposed TSs.

On the basis of its review, the NRC staff determined that the process descriptions in SHINE FSAR section 4b.4.2 provide a detailed account of the unirradiated SNM in process. Each operation with unirradiated SNM in receipt, transport, storage, and preparation for use is described in sufficient detail to show that there is reasonable assurance that these operations can be conducted safely. The storage, transport, and processing facilities and apparatuses are described in sufficient detail to provide confidence that the unirradiated SNM can be controlled throughout the process so that the health and safety of the public will be protected.

Based on the information presented in SHINE FSAR section 4b.4.2, the NRC staff finds that the description of the SHINE RPF unirradiated SNM processing and storage meets the acceptance criteria of the ISG augmenting NUREG-1537, Part 2 for the issuance of an operating license.

4b.4.5 Proposed Technical Specifications

In accordance with 10 CFR 50.36(a)(1), the NRC staff evaluated the sufficiency of the applicant’s proposed TSs for the SHINE RPF as described in SHINE FSAR chapter 4.

The proposed TS 2.1, SL 2.1.3 states the following:

SL 2.1.3	The pressure within process tanks containing irradiated uranyl sulfate in the RPF and connected piping up to the first valve shall be ≤ 18 psi gauge (psig).
Applicability	This specification applies at all times to the gauge pressure within the irradiated uranyl sulfate process tanks in the RPF. This specification also

	applies to piping and piping components, up to the first valve, that share a pressure boundary with the irradiated uranyl sulfate process tanks.

SL 2.1.3 provides that the process tanks containing irradiated uranyl sulfate in the TSSS, RLWS system, RLWI system, and radioactive drain system have a design pressure of 15 psig and have overpressure protection that prevents the design pressure from rising more than 3 psig above the design pressure. During normal operation, the PVVS ventilates the process tanks with a sweep gas to prevent the buildup of radiolytic hydrogen gas, which could lead to a deflagration or detonation resulting in an event that exceeds the design pressure. In the event of a loss of power or loss of flow through the PVVS, the N2PS provides a source of sweep gas stored in pressurized tanks containing nitrogen. The N2PS is designed to function during design basis events and will provide sweep gas for three days. The NRC staff determined that the tanks are hydrostatically tested to a pressure not less than 130 percent of design pressure, which is 19.5 psig, to ensure that they meet ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. The staff finds that SL 2.1.3 would prevent stresses on the tanks or piping that could exceed the allowable condition of the material. Therefore, the staff finds SL 2.1.3 acceptable.

4b.5 Review Findings

The NRC staff reviewed the descriptions and discussions of SHINE's RPF, as described in SHINE FSAR section 4b, 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 design of the RPF 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 RPF are sufficient and meet the applicable regulatory requirements and guidance and acceptance criteria for the issuance of an operating license.