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4.0 IRRADIATION UNIT AND RADIOISOTOPE PRODUCTION FACILITY DESCRIPTION

The facility description addresses the principal features, operating characteristics and parameters of the SHINE irradiation units (IUs) and Radiation Production Facility (RPF). 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 molybdenum-99 (Mo-99) and other fission products. The primary function of the RPF is to extract, purify, package, and ship medical isotopes.

This chapter of the SHINE construction permit (CP) safety evaluation report (SER) describes the review and evaluation by the U.S. Nuclear Regulatory Commission (NRC) staff (the staff) of the preliminary design of the SHINE IU and RPF as presented in Chapter 4, "Irradiation Unit and Radioisotope Production Facility Description," of the SHINE Preliminary Safety Analysis Report (PSAR), as supplemented by the applicant's response to the staff's requests for additional information (RAIs).

4a Irradiation Unit

SER Section 4a, "Irradiation Unit," provides an evaluation of the preliminary design of SHINE's IU as presented in SHINE PSAR Section 4a2, "Irradiation Facility Description."

4a.1 Areas of Review

The staff reviewed SHINE PSAR Section 4a2 against applicable regulatory requirements using appropriate regulatory guidance and standards to assess the sufficiency of the preliminary design and performance of SHINE's IU systems. As part of this review, the staff evaluated descriptions and discussions of SHINE's IU, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The preliminary design of SHINE's IU was evaluated to ensure the sufficiency of principle design criteria; design bases; and information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed SHINE's identification and justification for the selection of those variables, conditions, or other items, which are determined to be probable subjects of technical specifications for the facility, with special attention given to those items which may significantly influence the final design.

Areas of review for this section included the subcritical assemblies, neutron drivers, target solution vessel and light water pool, biological shield, nuclear design, thermal hydraulic design, and gas management system. Within these review areas, the staff assessed the preliminary analysis of the target solution, reactivity control mechanisms, neutron moderator and reflector, subcritical multiplication source, subcritical assembly support structure, neutron multiplier, high voltage power supply accelerator, control systems, accelerator and differential pumping system, target chamber, normal operating conditions, reactor core physics parameter, operating limits, design bases, and heat removal systems.

4a.2 Summary of Application

The SHINE facility includes eight irradiation units (IUs) and their supporting systems which comprise the irradiation facility. Section 4a2 of the SHINE PSAR describes one of the eight irradiation units. The summary provided below applies to all eight IUs.

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 molybdenum-99 (Mo-99) and other fission products. An accelerator is used to create deuterium-tritium fusion reactions, resulting in the formation of high-energy neutrons, which cause various multiplying reactions in the neutron multiplier, which then increase the neutron population entering the target solution vessel (TSV). The neutron population in the TSV leads to fissioning of the uranium solution.

Each IU consists of a subcritical assembly, neutron driver**,** target solution vessel and light water pool, biological shield, and gas management system. The primary fission-product barriers of the IUs are the target solution vessel (TSV), TSV off-gas system (TOGS), and TSV dump tank.

SHINE PSAR Section 4a2 provides the preliminary design of the SHINE IU systems, including physical descriptions, design bases, process functions and operation, safety functions, interfaces, and probable subjects of technical specifications.

SHINE PSAR Section 4b contains a summary description of the RPF. It describes the design of the RPF and the processes employed within it, includes the principal safety considerations that were factored into the RPF design, construction, and operation. It also describes the radioisotope production facility biological shield, the radioisotope extraction system, and the special nuclear material processing and storage.

4a.3 Regulatory Basis and Acceptance Criteria

The staff reviewed SHINE PSAR Chapter 4 against applicable regulatory requirements, using appropriate regulatory guidance and standards, to assess the sufficiency of the preliminary design and performance of SHINE's irradiation facility and radioisotope production facility in support of the issuance of a construction permit. In accordance with paragraph (a) of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.35, "Issuance of Construction Permits," a construction permit authorizing SHINE to proceed with construction may be issued once the following findings have been made:

(1) SHINE has described the proposed design of the facility, including, but not limited to, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public.
(2) Such further technical or design information as may be required to complete the safety analysis, and which can reasonably be left for later consideration, will be supplied in the final safety analysis report (FSAR).
(3) Safety features or components, if any, which require research and development have been described by SHINE and a research and development program will be conducted that is reasonably designed to resolve any safety questions associated with such features or components.
(4) On the basis of the foregoing, there is reasonable assurance that: (i) such safety questions will be satisfactorily resolved at or before the latest date stated in the application for completion of construction of the proposed facility, and (ii) the proposed facility can be constructed at the proposed location without undue risk to the health and safety of the public.

The staff's evaluation of the preliminary design of SHINE's IF and RPF does not constitute approval of the safety of any design feature or specification. Such approval will be made following the evaluation of the final design of SHINE's irradiation facility as described in the FSAR as part of SHINE's operating license application.

4a.3.1 Applicable Regulatory Requirements

The applicable regulatory requirements for the evaluation of SHINE's proposed IF and RPF are as follows:

- 10 CFR 50.23, "Construction permits"
- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
- 10 CFR 50.35, "Issuance of construction permits"
- 10 CFR 50.45, "Standards for construction permits, operating licenses, and combined licenses."

4a.3.2 Regulatory Guidance and Acceptance Criteria

The SHINE facility is not a nuclear reactor because it is not designed or used to sustain nuclear fission in a self-supporting chain reaction. The staff determined that while SHINE's IU is different from the Aqueous Homogeneous Reactor (AHR) described in the ISG, that guidance is still largely applicable.

The NRC staff evaluated SHINE's IU and RPF against the applicable regulatory requirements listed above, primarily using the guidance and acceptance criteria contained in Chapter 4, Section 4a2, "Aqueous Homogeneous Reactor Description" of the "Final Interim Staff Guidance [ISG] 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 (Reference 6), and "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 (Reference 7).

The use of additional guidance is based on the technical judgement 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 PSAR.

Specific acceptance criteria are provided in the section-by-section technical evaluation in Section 4a.4 and 4.b.4, "Review Procedures and Technical Evaluation," of this safety evaluation report (SER).

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

The staff performed a section-by-section evaluation of the technical information presented in SHINE PSAR Section 4a2, as supplemented by the applicant's responses to RAIs, to assess the sufficiency of the preliminary design and performance of SHINE's IU in support of the issuance of a construction permit, in accordance with 10 CFR 50.35(a). The sufficiency of the preliminary design and performance of SHINE's IU is demonstrated by compliance with applicable regulatory requirements, guidance, and acceptance criteria, as discussed in Section 4a.3, "Regulatory Basis and Acceptance Criteria," of this SER. The results of this section-by-section technical evaluation are described in SER Section 4a.5, "Summary and Conclusion."

For the purposes of issuing a CP, the preliminary design of the SHINE IU may be adequately described at a functional or conceptual level. The staff evaluated the sufficiency of the preliminary design of the SHINE IU based on the applicant's design methodology and ability to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety. As such, the staff's evaluation of the preliminary design of SHINE's IU does not constitute approval of the safety of any design feature or specification. Such approval will be made following the evaluation of the final design of SHINE's IU, as described in the FSAR, as part of SHINE's operating license application.

4a.4.1 Summary Description

The staff evaluated the sufficiency of SHINE's summary description of its IU, as described in SHINE PSAR 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.

As stated in Section 4a2.1 of the ISG Augmenting NUREG-1537, Part 2, the summary description of the IU should contain a general overview of the IU design and important characteristics of operation.

Based on the information provided in Section 4a2.1 of the SHINE PSAR, the staff finds that the summary description of the SHINE IU meets the applicable regulatory requirements and acceptance criteria of ISG Augmenting NUREG-1537 in support of the issuance of a construction permit in accordance with 10 CFR 50.35.

4a.4.2 Subcritical Assembly

The primary components that make up the subcritical assembly (SCAS) are the TSV 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 and located directly beneath the neutron driver assembly. It and the neutron driver assembly (NDAS) are the primary components of the IU. The SCAS, light water pool, and NDAS are further described in SHINE PSAR Sections 4a2.2.5, 4a2.4.2 and 4a2.3, respectively.

4a.4.2.1 Target Solution

The target solution is a uranyl sulfate solution with an enrichment of 19.75 percent +/- 0.2 percent. Uranium concentration is preliminary and subject to change until completion of detailed design. Fuel solution of this composition has been analyzed in a number of different research programs, as cited in SHINE PSAR Section 4a2.2.1.13. Based on these analyses, the chemical and physical characteristics of fuel constituents should be compatible with one another. Each irradiation cycle is 5.5 days, with some makeup solution expected to be added to counter process losses. Target solution processing is further described in SHINE PSAR Section 4b2.4.1.

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.

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. Detailed analyses of heat generation and cooling flow will be provided in the FSAR.

Non-uniformities, such as non-uniform void distribution, non-uniform temperatures, and non-uniform power distribution, are not expected to impact operational limits.

Off-gas formation is handled by the target solution off-gas system (TOGS), as described in SHINE PSAR Section 4a2.8. Preliminary calculations indicate that plutonium and poison buildup, along with changes in pH, will not be significant. The solution will also be processed through the molybdenum extraction and purification system (MEPS) after each irradiation cycle, and through the uranyl nitrate conversion system (UNCS) and the uranium extraction (UREX) system after a specified number of irradiation cycles. This processing sequence does not result in any long-term chemical or physical consequences to the target solution according to research conducted at Argonne National Laboratory (ANL) (ANL 2012).

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1, "Reactor Fuel," Acceptance Criteria, states, in part, that the PSAR should include a description of the "various phenomena that result in changes to the initial fuel composition…including potential fuel and fission product precipitation…" SHINE PSAR, Section 4a2.2.1.6, "TSV Operating Conditions," states that there is no precipitation out of the target solution, however IAEA TECDOC-1601, "Homogeneous Aqueous Solution Nuclear Reactors for the Production of Mo-99 [Molybdenum-99] and Other Short Lived Radioisotopes," states that as the fuel solution ages, fission products can approach solubility limits.

Therefore, in RAI 4a2.2-5 (Reference 14), the staff asked the applicant to provide information on how close the SHINE target solution will be to the solubility limits and to provide additional information discussing whether SHINE plans to use catalytic agents to mitigate precipitation, as discussed in SHINE PSAR, Section 4a2.4.1.1.

In response to RAI 4a2.2-5 (Reference 21), the applicant stated that as specified in Table 4a2.2-1 of the PSAR, a catalytic agent will be used in the target solution but there are no plans on using catalytic agents to mitigate fission product precipitation because the small amount of potential precipitation is expected to have an insignificant effect on reactivity in the TSV. The applicant also stated that the Table 4a2.2-1 of the PSAR will be updated with potential fission products precipitate levels and details of the system design to remove the precipitates from the target solution during processing (e.g., filter with differential pressure monitoring) will be provided in the FSAR. The staff will confirm that the final design conforms to this design basis during the evaluation of the SHINE's FSAR.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1, "Reactor Fuel," Acceptance Criteria, states, in part that the PSAR should include information on fuel operating parameters, taking into consideration "characteristics that could limit fuel barrier integrity." This should include temperature ranges during startup and normal operation. In RAI 4a2.2-6 (Reference

14), the staff asked the applicant to provide the normal temperature range for startup and approach to criticality.

In response to RAI 4a2.2-6 (Reference 20), the applicant responded that during startup and approach to criticality, the TSV is expected to be at approximately the same temperature as the PCLS, nominally 68°F, due to the small amount of decay heat generation in the target solution and the negligible fission power generated during startup.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1, "Reactor Fuel," states that the PSAR should include information on fuel operating parameters, taking into consideration "characteristics that could limit fuel barrier integrity." This should include irradiation times and burnup. In RAI 4a2.2-7 (Reference 14), the staff asked the applicant to provide the duration of the "short irradiation cycle" mentioned in SHINE PSAR, Section 4a2.2.1.9, "Chemical and Physical Changes in Target Solution," and the maximum expected burnup.

In response to RAI 4a2.2-7 (Reference 20), the applicant stated that an individual irradiation cycle is approximately 5.5 days, and the maximum expected target solution burnup is 0.55 percent of the initial heavy atoms (mainly U-235 and U-238), which would occur after approximately 5 years of operation at maximum power with no target solution makeup.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1, "Reactor Fuel," Acceptance Criteria, states, in part, that "maintaining fuel barrier integrity should be the most important design objective." SHINE PSAR, Section 4a2.2.1.10, "TSV Physical Structure," mentions a "credible deflagration." A strong deflagration or detonation could compromise the integrity of the primary system boundary. In RAI 4a2.2-8 (Reference 14), the staff asked that the applicant provide the pressure expected during a "credible deflagration," and discuss how this value was determined, as well as how it compares to the maximum pressure that each component of the primary system boundary can withstand.

In response to RAI 4a2.2-8 (Reference 21), the applicant stated in part, that "preliminary calculations indicate that the maximum pressure during a credible deflagration is less than 50 psig and the maximum pressure during a credible deflagration was determined by investigating possible modes of failure of the TSV Off-Gas System (TOGS… the calculated peak hydrogen concentration will be below the detonation limit. The deflagration pressure was calculated using an adiabatic flame temperature approach, adjusted for constant volume conditions, at the point of peak hydrogen concentration." The applicant committed to ensure that the design pressure of each component of the PSB will be greater than the credible deflagration pressure determined in the final calculations, which will be performed during detailed design. The staff will confirm that the final design conforms to this design basis during the evaluation of the SHINE's FSAR.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1, "Reactor Fuel," Acceptance Criteria, states, in part, that the application should provide a summary of the "fuel development, qualification, and production program." This should include discussions on fuel characterization, provide information on radiolytic gas production, changes in pH, gas removal, and addition of fuel and acid to the vessel along with implications on reactivity.

SHINE PSAR, Section 4a2.2.1.13, "Target Solution History," briefly describes some of the history of uranyl sulfate development, but does not describe SHINE's Target Solution Qualification Program. In RAI 4a2.2-9 (Reference 14), the staff asked the applicant to provide a description of SHINE's Target Solution Qualification Program, including specific historical target solution data and their origin (references) that have been used for validation and safety calculations presented in the current SHINE PSAR. The staff requested that the response include tests, experiments, and analyses that will be (or have been) performed to validate the historical data.

In response to RAI 4a2.2-9 (Reference 21), the applicant provided the SHINE Target Solution Qualification Program which contains historical target solution data, the means to produce the target solution, an overview of the processes to which the target solution is exposed, limits to ensure safe and reliable target solution performance, and the tests and experiments that will be and have been performed to validate the target solution characteristics. The staff finds that this response satisfies the acceptance criteria of the ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.1.

4a.4.2.2 Reactivity Control Mechanisms

The IU is not intended to achieve criticality during normal operation, so no control rods are included in the design. Reactivity is determined by seven variables: uranium concentration in the target solution, uranium enrichment, TSV fill-volume, target solution temperature, target solution pressure, temperature of the light water pool, and temperature of the primary closed loop cooling system (PCLS). During operation, the last four can be manipulated to control reactivity, while the others are generally not altered. The systems used to control system reactivity are described in detail in SHINE PSAR Section 7a2.4 and Chapter 7 of this SER has an in-depth evaluation of SHINE's IU reactivity control systems and engineered safety features actuation system.

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, as discussed in SHINE PSAR Section 4a2.3. The target solution can also be drained into criticality-safe dump tanks, as discussed in SHINE PSAR Section 4a2.4.1.

4a.4.2.3 Neutron Moderator and Reflector

The light water pool, which surrounds the TSV, provides neutron moderation and reflection, as described in SHINE PSAR Section 4a2.4.

The neutron multiplier is an aluminum clad annulus of material that serves to improve the neutron population in the TSV. The design features of the multiplier are described in SHINE PSAR Section 4a2.2.6. A review of the neutron multiplier and conclusion can be found in Section 4a.4.2.6 of this SER.

No additional neutron moderators or reflectors are included in the design.

4a.4.2.4 Subcritical Multiplication Source

The subcritical multiplication source is a fixed neutron source that is used to monitor reactivity when the neutron driver is not operating. Its output is several orders of magnitude less than the neutron driver and is more suitable for performing 1/M measurements during startup. This allows for accurate and reliable measurement of neutron multiplication while filling the TSV with target solution. Specific details of the neutron multiplication source will be provided in the applicant's FSAR. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

4a.4.2.5 Subcritical Assembly Support Structure

The subcritical assembly support structure (SASS) maintains the location and shape of the aqueous 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 the cooling paths and acts as an additional fission product barrier in the event of a TSV failure.

The SASS is designed to conservatively hold the weight of 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.

The SASS is operated at pressures near atmospheric (a slight pressure differential is required across the SASS to provide cooling water flow). The SASS is designed for an internal pressure of 100 pounds per square inch to accommodate forces resulting from a hydrogen deflagration event followed by a failure of the TSV integrity.

The materials used to construct the SASS are chosen due to their compatibility with the chemical environment and demonstrated performance under a neutron flux.

The proposed design of the SASS appear to meet the acceptance criteria of the ISG Augmenting NUREG-1537, Part 2, Section 4a2.2.5, "Reactor Internals Support Structures." The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

4a.4.2.6 Neutron Multiplier

The neutron multiplier is located in the space between the neutron driver tritium target chamber and the target solution vessel. It is an annulus of aluminum-clad material that moderates and multiplies the fast neutrons from the fusion reactions initiated by the neutron driver. Heat deposited in the multiplier is removed by the light water pool system (LWPS). The temperature profiles through the multiplier will be determined during detailed design, with appropriate design features included to address any thermal expansion and contraction expected to occur. Its design lifetime is 30 years, but can be removed and replaced if damaged. The construction materials for the proposed design are compatible with the chemical and radiation environment. SHINE's PSAR, Section 4.2a2.6, states that in the event of a cladding failure, there are no consequences that would affect the safe operation and shutdown of the irradiation system and that a breach of the aluminum cladding will be detected by sampling of the LWPS. Contaminated water can be sent for processing via the UNCS. The FSAR will contain a more comprehensive description of the manufacturing techniques and final dimensions for the neutron multiplier. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

4a.4.2.7 Subcritical Assembly Findings

The fuel 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 historical data described in SHINE PSAR Section 4a2.2.1.13. The operating conditions and chemical and physics properties of the target solution are described in detail.

The proposed design for the subcritical assembly support structure 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.

The FSAR will contain more detailed discussions on several topics addressed in the SHINE PSAR. These include the subcritical multiplication source, the neutron multiplier, the light water pool, behavior of the TSV during a credible deflagration, and the final description of the target solution qualification program.

The description of the subcritical assembly and its components, including operating limits and operating conditions, is adequate and should be sufficient to ensure the protection of the public and minimize danger to life or property, consistent with 10 CFR 50.34 and 10 CFR 50.35. On the basis of its review, the staff finds that the level of detail provided on the subcritical assembly demonstrate an adequate design basis in support of preliminary design and satisfies the applicable acceptance criteria of the ISG Augmenting NUREG-1537, Part 2. Therefore, the staff concludes that the applicant's descriptions of the equipment, facilities and procedures are adequate for the granting of a construction permit.

4a.4.3 Neutron Driver

The NDAS is an accelerator-driven system that produces 14 million electron volts (MeV) neutrons via deuterium-tritium fusion reactions. The NDAS is the source of neutrons used to generate the neutron fluxes required to create medical isotopes in the TSV which holds the target solution. These high-energy neutrons enter the target solution initiating the resulting subcritical fission reactions. The NDAS is situated above the subcritical assembly and mounted to the cell wall. The NDAS consists of the neutron driver, high voltage power supply, and a control cabinet.

While the ISG Augmenting NUREG-1537 does not have a section dedicated to the neutron driver assembly system (NDAS), which is unique to SHINE, the staff assessed that in alignment with 10 CFR 50.34(a)(4), which requires a "preliminary analysis and evaluation of the design and performance of structures, systems, and components of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility…, and the adequacy of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents," the PSAR should include information regarding corrosion control, susceptibility to radiation damage, and the physical description, including materials and physical dimensions. Therefore, the staff asked, in RAI 4a2.3-1 (Reference 14), that the applicant provide the physical characteristics of the NDAS (e.g., construction materials, dimensions), provide the expected activity of the NDAS due to activation of its components at the end of one irradiation cycle and at the end of its expected life, and describe what radiation damage concerns there are for affected materials and components.

In response to RAI 4a2.3-1 (Reference 20), the applicant provided a preliminary design with the description of the materials and dimensions of the NDAS. In addition, the applicant stated that the materials or components of the NDAS do not have radiation damage concerns. Materials known to have unacceptably low radiation damage thresholds, such as Teflon, will not be used in the NDAS which will be made from materials suitable for the expected neutron fluence levels. The applicant also stated that the NDAS is expected to have an operational life expectancy primarily determined by 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 staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

4a.4.3.1 High Voltage Power Supply

This 300 kilovolt (kV) high voltage power supply (HVPS) provides voltage to the accelerator, as discussed in SHINE PSAR Section 4a2.3.3. It is controlled via the control system, as described in SHINE PSAR Section 4a2.3.2, and shuts down on an overvoltage greater than 320 kV (a protective feature and not a safety limit or function).

4a.4.3.2 Control System

This control system is the interface for the NDAS. It provides the means to energize, monitor, and change NDAS components.

4a.4.3.3 Accelerator and Differential Pumping System

The differential pumping system in SHINE PSAR Figure 4a2.3-3 depicts the ion source, accelerator, focus element, target chamber, and the three differential pumping stages in the NDAS. Deuterium ions are fed via an ion extractor from the ion source to the accelerator. The HVPS powers the 300 kV accelerator, which accelerates the ions towards the focus element. The differential pumping stages maintain the very low pressure between the accelerator and the target chamber. The target chamber is maintained at low pressure and is where the bulk of the deuterium-tritium (D-T) interactions that drive the subcritical reaction occur.

Due to the high voltage involved with the accelerator, there is potential for electromagnetic interference. To mitigate this, NDAS components that are exposed to potential electromagnetic interference from the accelerator are shielded or otherwise electrically isolated. Other components near the accelerator will be similarly shielded.

The beam of accelerated ions will diverge in the absence of the focusing element. Any failure of the focus element will result in a drop in neutron yield.

4a.4.3.4 Target Chamber

The target chamber is maintained at low pressure and filled with tritium gas. Neutron yield is typically determined by the purity of the tritium in the chamber, which is controlled via the tritium purification system. The ion beam is fully stopped in the chamber during normal operation, so any increase in pressure will not change the yield and a sufficient decrease in pressure will decrease the yield.

The target chamber 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.4.3.5 Process Control Requirements

The TSV process control system (TPCS) and TSV reactivity protection system (TRPS) interface with the NDAS control system and will trigger the shutdown of the HVPS via safety-related trip circuitry in the event of abnormal conditions.

4a.4.3.6 Neutron Driver Findings

The descriptions of the components of the NDAS are adequate and are sufficient to ensure the protection of the public and minimize danger to life or property, consistent with 10 CFR 50.34 and 10 CFR 50.35. Failure of any component of the NDAS will result in a conservative, lower flux state.

On the basis of its review, the staff finds that the level of detail provided on the NDAS demonstrates an adequate design basis in support of preliminary design and satisfies the applicable acceptance criteria of the ISG Augmenting NUREG-1537, Part 2. Therefore, the staff concludes that the applicant's descriptions of the equipment, facilities and procedures are adequate for the granting of a construction permit.

4a.4.4 Target Solution Vessel and Light Water Pool

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 PSAR Section 4a2.8.

4a.4.4.1 Target Solution Vessel

SHINE PSAR describes the physical characteristics of the TSV, including the physical dimensions of the TSV and supporting structures. SHINE PSAR also states that the TSV is designed and fabricated following the intent of the ASME Boiler and Pressure Vessel Code, Section III. Ongoing research at Oak Ridge National Laboratory (ORNL) is intended to determine whether the TSV design, fabrication process, and construction materials satisfy the requirements described in the code.

In response to RAI 4a2.4-1 (Reference 14), which asked the applicant to provide a discussion of the applicable ASME Code and discuss the features of the SHINE design that prevent application of the code as written, the applicant responded (Reference 21) that though the TSV will be designed and fabricated following the intent of the ASME Boiler and Pressure Vessel Code (BPVC), Section III, the TSV will not be certified to Section III of the ASME BPVC because its fabrication material is not included in ASME BPVC Section II. The applicant added that the results from the irradiation and corrosion testing being performed at ORNL will inform the final design of the TSV, which is expected to be completely described in the FSAR. The results of the testing at ORNL will also verify that the stress intensity encountered by the TSV under design loadings during the design lifetime does not exceed the allowable stresses of the TSV material, including postulated accident loadings, which will be factored into the TSV design parameters. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

SHINE PSAR, Section 4a2.4.1.5, "Chemical Interactions and Neutron Damage," states that a materials surveillance and inspection program for the TSV and other primary system boundary (PSB) components will be described in the final safety analysis report (FSAR). In RAI 4.2.4-2, the staff asked the applicant to provide a list of surveillance and inspection requirements, as well as information to show that the design will allow the required periodic surveillance and inspections to be performed.

In response to RAI 4a2.4-2 (Reference 21), the applicant committed to provide surveillance and inspection capabilities for these components in order to assess mechanical integrity and verify corrosion rates are acceptable. The staff will confirm that the final design conform to this design basis during the evaluation of SHINE's FSAR.

4a.4.4.2 Light Water Pool

The TSV is located inside the light water pool, with the top of the TSV 6 feet below the water's surface. It is constructed from concrete and lined with stainless steel and is designed to withstand the chemical environment of the target solution.

SHINE PSAR, Section 4a2.4.2.1, "Design of Light Water Pool," states that the steel liner of the light water pool is designed to withstand the chemical environment of the target solution in the event of a breach that leaks target solution into the pool. However, if any accumulation or plateout of fission products occurred on the liner surfaces (including corners, imperfections on weld points, etc.), this could lead to increased local dose rates that might challenge the limits in 10 CFR Part 20, "Standards for Protection Against Radiation." In RAI 4a2.4-3 (Reference 14), the staff asked the applicant to provide information discussing whether the design characteristics of the pool liner preclude any accumulation or plateout of fission products that could challenge the limits in 10 CFR Part 20.

In response to RAI 4a2.4-3 (Reference 20), the applicant stated, in part, that:

> Under normal operating conditions, the target solution does not come in contact with the light water pool or the light water pool steel liner. The target solution is located inside the PSB, which consists of the TSV, the TOGS, and the TSV dump tank. As described in Subsection 4a2.2.1.4, the PSB components are designed to be compatible with the target solution to avoid corrosion and other unwanted metallurgical effects that could lead to the PSB being compromised. Additionally, the TSV is located within the SASS pressure boundary. The SASS, along with the PCLS, provides another barrier between the target solution and the light water pool, should a leak in the TSV develop. The closed loop design of the PCLS prevents the commingling of the PCLS coolant with the water in the light water pool….In the event of a breach in which the target solution leaked into the light water pool, the IU cell where the leak is occurring would be shut down. The UNCS may then be used to process the contents of the light water pool by separating out the uranium and passing the contaminated water on for downstream processing. The IU cell would then be decontaminated by wash downs or other suitable means, as needed.

4a.4.4.3 Target Solution Vessel and Light Water Pool Findings

The description of the TSV and light water pool, including operating limits and operating conditions, is adequate and should be sufficient to ensure the protection of the public and minimize danger to life or property, consistent with 10 CFR 50.34 and 10 CFR 50.35. The TSV is conservatively designed to fail to a safe, non-critical geometry and its components are adequately designed to withstand operational and credible accidents environment. The light water pool provides cooling to the TSV and provides an additional layer of protection against radiation damage for local components. On the basis of its review, the staff finds that the level of detail provided on the target solution vessel and the light water pool demonstrates an adequate design basis in support of preliminary design and satisfies the applicable acceptance criteria of the ISG Augmenting NUREG-1537, Part 2. Therefore, the staff concludes that the applicant's descriptions of the TSV and light water pool are adequate for the granting of a construction permit.

4a.4.5 Irradiation Facility Biological Shield

The staff evaluated the sufficiency of the preliminary design of SHINE IF biological shield, as described in SHINE PSAR Section 4a2.5.2, "Biological Shield Design Basis," in part by reviewing the design bases for the materials to be included in the biological shield design using the guidance and acceptance criteria from Section 4a2.4, "Biological Shield," of the ISG Augmenting NUREG-1537, Parts 1 and 2.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.4, "Biological Shield," Acceptance Criteria, states, in part, that "the principal objective of the shield design should be to ensure that the projected radiation dose rates and accumulated doses in occupied areas do not exceed the limits of 10 CFR Part 20, 'Standards for Protection Against Radiation,' and the guidelines of the facility's ALARA (as low as reasonably achievable) program . . .." In order to determine the adequacy of the shielding design, in RAI 4a2.5-1 (Reference 14), the staff asked the applicant to provide a list of the components inside the irradiation unit cell that are considered significant contributors to the gamma and neutron flux and dose rates at locations that could be occupied as well as to the unrestricted environment.

In response to RAI 4a2.5-1 (Reference 21), the applicant stated that the components inside the IU cell that are considered to be significant contributors to the gamma and neutron fluxes are the neutron driver and the Subcritical Assembly System (SCAS). The applicant also provided the magnitude of the contributions from both the neutron driver and the SCAS.

In accordance with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 4a2.4, the staff confirmed that the objectives of the shield design bases are sufficient to ensure the protection of the public and minimize danger to life or property, consistent with 10 CFR 50.34 and 10 CFR 50.35. The biological shield is designed to meet the goals described in Chapter 11 of the SHINE PSAR, and meets or exceeds the requirements in 10 CFR Part 20, "Standards for Protection Against Radiation." The proposed materials and configuration are consistent with staff-endorsed guidance (American Nuclear Standards Institute [ANSI]/American Nuclear Society [ANS]-6.4.2-2006, "Specification for Radiation Shielding Materials" [ANS/ANSI 2006]; American Concrete Institute [ACI] 349-06, "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary," [ACI 2007]; and Regulatory Guide 1.69, Revision 1, "Concrete Radiation Shields and Generic Shield Testing for Nuclear Power Plants" (Reference 37). The results of the proposed analyses will be presented in the FSAR and will ensure that the final design of the biological shield meets all regulatory requirements. Therefore, the staff concludes that the applicant's descriptions of the equipment, facilities and procedures are sufficient to support the issuance of a construction permit.

4a.4.6 Nuclear Design

The IU comprises the biological shield, the NDAS, the LWPS, the SCAS, and the neutron flux detection system. The IU supporting systems include the TOGS, the tritium purification system (TPS), and the PCLS. The irradiation facility contains eight IUs that share two TPSs. Using the guidance and acceptance criteria from Section 4a2.5 “Nuclear Design,” of the ISG Augmenting NUREG-1537, Parts 1 and 2, the staff will evaluate the nuclear parameters and characteristics of the facility to determine whether the system can be operated and shut down safely from any operating condition.

4a.4.6.1 Normal Operating Conditions

The SCAS operates under three modes that are relevant to nuclear design: Mode 1, startup mode; Mode 2, irradiation mode; and Mode 3, post-irradiation mode. A fourth mode is described in SHINE PSAR Chapter 7 and is not discussed in this chapter. In each case, the IU can be shut down by the control systems (TRPS and TPCS), which will trip on high PCLS temperature or high flux. As an additional administrative control, the operators can manually dump the contents of the TSV to the dump tanks, 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 criticality-safe dump tanks. There are two completely independent dump valves, along with independent dump lines and overflow lines. The dump valves fail open and can be triggered by the TRPS, TPCS, and the operator. The staff has also reviewed additional details describing the drain rate, trip signal delay, and valve opening time, which were submitted in SHINE’s responses to the staff’s RAIs.

The target solution will be processed through the UNCS after it has been through a specified number of irradiation cycles. The burn-up after this amount of exposure is very small, with less than 0.02 percent of uranium-235 (U-235) undergoing fission. Shine estimates that xenon and samarium accumulation will reduce operating neutron multiplication and fission power by less than 10 percent relative to a system without xenon-135 and samarium-149. A complete analysis of the effects of poison and plutonium buildup will be submitted in the FSAR.

The proposed design describes the reactivity and reactivity changes of the system during all modes of operation, including reactivity worths 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 TPCS 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 a criticality from occurring are sufficient.

Minor power oscillations during operation are expected, but should be small and self-limiting due to the low power density and negative temperature coefficients. In the case of a TOGS failure, the resulting void collapse will cause a small reactivity increase, but not large enough to result in a criticality. A complete analysis of TSV kinetics will be provided in the FSAR.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.5.1, “Normal Operating Conditions,” states that the PSAR should give reactivity worths for control rods, reflector units, and other in-core components for all anticipated configurations. While some information is presented on coefficients of reactivity in SHINE PSAR Section 4a2.6.4, additional information is needed to verify that the SHINE IUs will not become critical under any phase of operation. In RAI 4a2.6-3 (Reference 14), the staff asked the applicant to compare the reactivity worths of all components in the IU to the margin to criticality in the TSV for all phases of operation.

In its response to RAI 4a2.6-3 (Reference 21), the applicant stated, in part, that in Mode 1, startup conditions:

> the TSV is designed to be filled with uranyl sulfate solution to a level that is approximately five percent by volume below critical… While the SHINE TSV is not a reactor, there are two moveable components identified within the nuclear assembly that have the potential for significant reactivity effects. These two components are the tritium chamber and the neutron multiplier. Removing the neutron multiplier and flooding the tritium chamber with water from the Light Water Pool System (LWPS) were calculated to both have negative reactivity effects, thus increasing the margin to criticality.

As the SHINE system transitions from Mode 1, startup conditions, to Mode 2, irradiation conditions, the keff of the system decreases. Replacing the neutron multiplier and flooding the tritium chamber with water from the LWPS were calculated to both have negative reactivity effects, thus increasing the margin to criticality. The staff will confirm that the final design conforms to this design basis during the evaluation of the SHINE's FSAR.

The SHINE subcritical assembly cooling includes a Primary Closed Loop Cooling System (PLCS) and an LWPS cooling loop. A pipe break in one of the cooling systems or other means of introducing voids, lowering the coolant density in the system, could result in a reactivity insertion. To determine if voiding out the cooling system could turn the TSV from a subcritical system into a critical reactor, in RAI 4a2.6-4 (Reference 14), the staff asked the applicant to provide reactivity worth for voiding out the cooling system over the full range from nominal coolant temperature and density to a fully voided cooling system

In response to RAI 4a.2.6-4 (Reference 21), the applicant provided reactivity changes due LWPS and PCLS voids. The data provided shows that for the PCLS, there is a negative insertion of reactivity as the percent void increases. In the LWPS, a significant amount of void (> 20 percent) must be present to add a substantial amount of reactivity at startup conditions. The applicant stated, in part, that:

> The design will prevent introduction of significant amount of void into the subcritical assembly, such as the use of a delay tank to vent entrained voids located downstream of the LWPS cooling pump. Positive pressures are expected in the piping line downstream of the LWPS cooling pump, which will prevent the introduction of void since a break in the line would result in the loss of water rather than the ingress of air. Flow meters and pressure detection on the LWPS are planned, which would also indicate if a significant amount of air had entered the pump since the output pressure and flow will decrease.

The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.5.1, "Normal Operating Conditions," states that there should be systems that are "sufficiently redundant and diverse to control all proposed excess reactivity safely and to safely shut down the reactor and maintain it in a shutdown condition." The SHINE irradiation unit system relies on dumping the solution to the TSV dump tank under abnormal conditions. SHINE PSAR, Section 4a2.6.3.6, "Redundancy and Diversity of Shutdown Methods," states that the dump system has redundant dump valves. In RAI 4a2.6-8 (Reference 14), the staff asked the applicant to provide additional information on the design drain rate of the TSV when the dump valves are open, the delay time from the drain valve open signal until the valves start to open, and the duration of time it takes the dump valves to open.

In response to RAI 4a2.6-8 (Reference 21), the applicant noted that the TSV drain system is designed to drain a minimum of 20 gallons per minute (gpm) when the dump valves are open (design drain rate is conservatively based on only one drain line available); the delay time between the conditions that would trigger a dump signal and the start of the dump valves opening will be a maximum of one second; the duration of time it takes for the dump valves to open will be less than 5 seconds. The staff will confirm that the final design conforms to this design basis during the evaluation of the SHINE's FSAR.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.5.1, "Normal Operating Conditions," Acceptance Criteria, states, in part, "the reactivity impacts of radiolytic gas and void formation, fission product gas removal, fuel solution and acid addition, and condensate return to the core should be provided." This analysis should also include the evaporation of water. SHINE PSAR, Section 4a2.6.1.1, "Gas Management System Effects," states in part, "the radiolysis of water in the system causes an anticipated increase in reactivity during operation…" The SHINE PSAR infers that water is constantly leaving the TSV through radiolysis and evaporation. A certain amount of water will be held up outside the TSV as it goes through the recombination and condensation process before it is returned to the TSV, increasing the reactivity in the system.

In RAI 4a2.6-9 (Reference 14), the staff asked that the applicant provide quantitative estimates of the water inventory outside of the TSV, the reactivity increase caused by removing that water from the TSV, and the increase in fuel solution concentration.

In response to RAI 4a2.6-9 (Reference 21), the applicant stated that a small percentage of the water volume of the TSV may be held up outside of the TSV in the TOGS. The reactivity increase caused by removing that water from the TSV during irradiation mode has been estimated to be a small reactivity increase is small in comparison to the expected subcritical reactivity of the SHINE system during irradiation mode. The staff will confirm that the final design conforms to this design basis during the evaluation of the SHINE's FSAR.

4a.4.6.2 Reactor Core Physics Parameters

A variety of codes will be used to calculate various nuclear physics parameters. Monte-Carlo N-Particle Transport Code-5 (MCNP5) will be used to calculate neutron flux, reactivity, dose rates, neutron lifetime, and reaction rates. COUPLE, part of the NRC's SCALE code, will be used to calculate flux-dependent cross-sections and fission yields. ORIGEN will be used to generate source term concentrations and activities following various irradiation and decay intervals. The staff has also reviewed SHINE's uncertainty analysis for the calculations using these codes, which was submitted in its responses to the staff's RAIs. These calculations will be compared to benchmark experiments for validation.

Preliminary calculations show that target solution void, temperature, and power coefficients will generally be negative for all modes of operation. The temperature coefficients for the PCLS and LWPS may not be negative during some conditions, but it is expected that this will not result in strong negative feedback. The target solution temperature coefficient should be the most significant because the majority of the heat is deposited directly in the target solution. SHINE's analyses show that the combined reactivity coefficients should be sufficiently negative over the anticipated range of operating conditions.

4a.4.6.3 Operating Limits

While specific values for operating limits will not be available until the FSAR is complete, SHINE PSAR discusses some requirements. Void coefficients should be negative throughout all operating conditions, and combined reactivity coefficients should be sufficiently negative over the anticipated range of operating conditions, as described in SHINE PSAR Section 4a2.6.2. The target solution burn-up should be minimal in the SCAS.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.5.2, “Reactor Core Physics Parameters,” states, in part, that “the applicant should present information on core physics parameters that determine reactor operating characteristics….” The SHINE PSAR did not discuss the effects of xenon-135 and samarium-149 on the TSV operation irradiation cycle. In RAI 4a2.6-5 (Reference 14), the staff asked the application to provide an estimate of the reactivity due to xenon-135 and samarium-149 over the cycle and its effect on neutron multiplication and fission power, since the time required to establish equilibrium xenon and samarium is significant compared to the length of an irradiation cycle.

In response to RAI 4a2.6-5 (Reference 21), the applicant stated that the worth of fission product poisons such as xenon and samarium are small compared to the temperature and void defects.

In RAI 4a2.6-6 (Reference 14), the staff asked the applicant to provide an uncertainty analysis for the reactivity worths, coefficients, and k_{eff} values.

In response to RAI 4a2.6-6 (Reference 21), the applicant stated, in part, that “reactivity worths coefficients, and k_{eff} values are calculated using MCNP5, version 1.60 … SHINE does not plan to use the absolute k_{eff} predictions from MCNP as the basis to determine operating k_{eff} of the subcritical assembly. Instead, SHINE plans to use a volume margin-to-critical approach coupled with the calculated reactivity worth of that volume….” SHINE will also ensure that the detector, source, and subcritical assembly geometry result in conservative 1/M shapes to ensure that early predictions of critical volume are lower than actual critical volume and result in lower actual k_{eff} values. A validation plan to validate the neutronics predictions will be included with the SHINE Operating License (OL) application. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE’s FSAR.

There are only three initiating events that may result in inadvertent insertions of excess reactivity: excessive cooldown of the TSV, increased pressure in the TSV, and excess volume of target solution. None of these events should result in damage to the PSB. These events are described in SHINE PSAR Section 13a2.1.2. In the event of a loss of power, the neutron driver will de-energize and the target solution will be transferred to criticality-safe dump tanks.

The core configuration with the highest power density should be analyzed as a basis for safety limits. A complete evaluation of technical specifications, limiting conditions for operation (LCOs), and surveillance requirements will be performed during the review of SHINE’s operating license application.

4a.4.6.4 Nuclear Design Findings

SHINE PSAR gives an adequate description of the proposed configuration of the SCAS during the three relevant modes of operation. Target solution behavior during operation has been adequately addressed, including gaseous fission product buildup and removal, poisons, and power oscillations. Reactivity analyses include reactivity values for the in-core components.

Analyses of neutron lifetime, effective delayed neutron fraction, and coefficients of reactivity are in progress or have been completed using methods validated at similar reactors and experimental measurements. Final values for all reactor physics parameters will be presented in the FSAR.

The descriptions of the nuclear design component of the facility are adequate and are sufficient to ensure the protection of the public and minimize danger to life or property, consistent with 10 CFR 50.34 and 10 CFR 50.35. Therefore, the staff concludes that the applicant's descriptions of the equipment, facilities and procedures are sufficient to support the issuance of a construction permit.

4a.4.7 Thermal-Hydraulic Design

The applicant provided a description of the systems that are responsible for target solution inventory control and heat removal during irradiation and shutdown operations for the eight IUs. The staff evaluated the sufficiency of the preliminary design of SHINE's thermal hydraulic design, as described in SHINE PSAR Section 4a2.7, "Thermal Hydraulic Design," in part by reviewing the information and analyses submitted to show that sufficient cooling capacity exists to prevent target solution overheating and loss of target solution barrier for anticipated system operating conditions, using the guidance and acceptance criteria from Section 4a2.6, "Thermal-Hydraulic Design," of the ISG Augmenting NUREG-1537, Parts 1 and 2.

The ISG Augmenting NUREG-1537, Part 2, Section 4a2.6, "Thermal-Hydraulic Design," states, in part, that the applicant should discuss possible system "instability following perturbation to the system (including from radiolytic gas generation)." In RAI 4a2.7-1 (Reference 14), the staff asked the applicant to provide linear stability analysis of the full system and an analysis and discussion of the expected bounds of any expected oscillations.

In response to RAI 4a2.7-1 (Reference 21), the applicant provided a linear stability analysis and stated, in part, that:

> . . . [the] subcritical accelerator-driven fissile solution systems were found to be unconditionally stable in the linear approximation. Perturbations from the TOGS can result in pressure changes in the TSV. However, these pressure changes only serve to impose a reactivity feedback term, and do not alter the [conclusions in the analysis].
>
> Oscillations in TSV fission power are expected to be the result of coupled system oscillations, principally due to potential pressure variations in the TOGS and source oscillations from the neutron driver. Pressure variations in the TOGS at the TSV are expected to be less than 0.5 psi, and this pressure change has been estimated to minimally affect TSV reactivity during irradiation. . . This change in reactivity is estimated to result in [a minimal] change in TSV power.

> Oscillations in the neutron driver neutron output are expected to be less than three percent from the target neutron output. With a subcritical assembly and no feedback effects, a change of three percent in the neutron source term would result in a three percent change in the output of the assembly. Due to negative temperature and void reactivity coefficients, the oscillations from this source variation will be less than three percent.
>
> Total oscillations in TSV fission power are expected to be [small] due to potential superposition of these sources of oscillation. As described in Subsection 4a2.6.1.2 of the SHINE PSAR, results of transient modeling of power oscillations using a dynamic model and reactivity feedback effects will be provided with the FSAR.

The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

4a.4.7.1 Heat Removal Systems

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, the LWPS, and the TOGS.

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 the PCLS water, then flows to reject the heat through a heat exchanger in the radioisotope process facility cooling system (RPCS).

The LWPS cooling loop removes heat from the neutron multiplier and from the neutron driver tritium target chamber using forced convective flow. Energy can also be deposited into the LWPS coolant by neutron and gamma radiation. The LWPS also removes heat from the light water pool. 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 dump tank when it contains the irradiated target solution. The LWPS cooling water rejects heat to the RPCS. 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 Coolant Hydraulic Characteristics of the Target Solution

The PCLS removes heat from the TSV during irradiation and shut down operations. The PCLS volumetric coolant flow rate is 4.7 liters per second (L/s). The coolant water enters at 20 degrees Celsius (°C) and exits at 26.7 °C. 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 so that the pressure difference cannot be maintained, then some of the radioactive target solution could leak into the PCLS cooling water. The nominal temperature of the solution in the TSV is 60 °C. The operating conditions in the TSV should prevent plate out of chemicals on the PCLS heat transfer surfaces.

A loss or degradation of the PCLS cooling system would cause an increase in the target solution temperature. If 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 light water pool is cooled by the LWPS. In cases that the LWPS 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. The heat capacity of the pool is large enough that the pool temperature will increase by only 11.8 degrees Fahrenheit (°F) from 90 days of decay heat load.

4a.4.7.3 Target Solution Thermal Power Density Distribution

The applicant has not provided power density distribution in the target solution. The fission power density should have 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 slowing down of the fission fragments. 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 should drive gradients in fluid temperature and void fraction that enhance natural circulation in the target solution.

4a.4.7.4 Thermal-Hydraulic Methodology

The applicant will use a correlation based thermal-hydraulic methodology for safety calculations in the FSAR for calculations involving fluid flow and convective heat transfer. The heat transfer in structures will solve conduction heat transfer equations. The nuclear heat generation rates will be calculated using MCNP5.

Detailed thermal-hydraulic design optimization calculations will use Computational Fluid Dynamics (CFD) software including Fluent and CFX that include volumetric heat and gas generation sources. The calculations are used to estimate the steady state target solution temperature, which is determined by the balance of the heat generation and the heat removal to the 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 be used to determine the expected range of heat transfer coefficients and void fractions. They were also used to validate CFD calculations.

Details of the methodologies including validation of the methods and calculation results will be provided in the FSAR.

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

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 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 Los Alamos National Laboratory (LANL) and documented in the 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 any oscillations should be damped. Driven 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 will be accounted for in the final design. The void formation should enhance the heat transfer in the TSV due to increased natural circulation flows due to buoyancy effects. The natural circulation should also help 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 earlier that provide heat removal from the TSV. The cooling system design basis and details of the PCLS and LWPS are provided in Chapter 5 of the SHINE PSAR.

4a.4.7.7 Cooling Performance

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.4.7.8 Bulk Boiling of the Target Solution

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. The TRPS system will shut down the neutron driver and dump the target solution to the TSV dump tank. This should prevent 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 primary system boundary and will not present a radiation hazard.

4a.4.7.9 Thermal-hydraulic Design Findings

The staff has reviewed the thermal-hydraulic design of the IU. The thermal-hydraulic design considers the dominant design considerations for heat removal, cover gas control, and target solution control. The staff concludes that the SHINE facility 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 conditions under normal and abnormal conditions. The heat transfer coefficients that would be required to maintain the assumed design conditions should be achievable. Adequate heat removal through natural circulation and convection within the pool is also provided for decay heat generation in the TSV dump tank. The fluid and structures temperatures and heat fluxes eliminate concerns about CHF in all cases. The TOGS has the recombination and condensation capacity to control the cover gas operating conditions and maintain them within normal operating parameters. The potential technical specifications that have been proposed are adequate to maintain operating conditions within acceptable limits. The staff concludes that the proposed preliminary thermal-hydraulic design of the IU is sufficient to support the issuance of a construction permit.

4a.4.8 Gas Management System

The staff evaluated the sufficiency of the preliminary design of SHINE's gas management system, as described in SHINE PSAR Section 4a2.8, "Gas Management System," by using the guidance and acceptance criteria from Section 4a2.7, "Gas Management System," of the ISG Augmenting NUREG-1537, Parts 1 and 2.

The TSV off-gas management system (TOGS) removes gaseous fission products and radiolytic gasses from the TSV during operation of the irradiation unit. The hydrogen recombiners prevent the hydrogen concentration from reaching a level where a deflagration or detonation could occur. This also serves to conserve water in the system. The TOGS also condenses water vapor and returns the water to the TSV. The construction materials used for the TOGS must be compatible with the expected chemical environment, and no credible scenarios should result in a loss of confinement as a consequence of corrosion. The geometry of the TOGS should preclude criticality even if filled with the target solution.

In accordance with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 4a2.7, "Gas Management System," the staff should confirm that the design of the gas management system and the associated analysis are sufficient to provide reasonable assurance of safe operation of the reactor and compliance with all applicable chemical and radiological release criteria.

Therefore, in RAI 4a2.8-1 (Reference 14), the staff asked the applicant to provide the TSV operating condition envelope and design assumptions for the TSV off-gas recombiner system, including assumed design margins.

In response to RAI 4a2.8-1 (Reference 21), the applicant provided the TSV operating envelope, the TOGS design assumptions for the gas leaving the TSV headspace during normal operation, and the assumed design margins of the TOGS components.

In RAI 4a2.8-2 (Reference 14), the staff asked the applicant to provide the basis for an "alert to the operator" at a hydrogen concentration of 2.5 percent and automatic shutdown of the neutron driver at 3 percent and to discuss whether there is sufficient margin to the deflagration limits at these values. The staff also asked the applicant to provide information indicating where the measurement of the hydrogen concentration is taken.

In response to RAI 4a2.8-2 (Reference 21), the applicant stated, in part, that:

> . . . normal operation of the TOGS maintains hydrogen concentrations at or below two percent in the off-gas. The alarm setpoint of 2.5 percent is slightly higher than normal operating conditions to provide advanced warning of abnormal conditions to the operator prior to reaching the trip setpoint, while not resulting in excessive alarms that distract the operators in the Control Room. The hydrogen concentration trip point of three percent provides approximately 33 percent margin to the lower flammability limit of four percent. The hydrogen concentration trip point ensures that the initial hydrogen concentration in the TOGS is sufficiently low in the event of an abnormal condition, such as a blower malfunction.
>
> The margin to the deflagration limit is sufficient because it is not expected that the hydrogen concentration would reach four percent in the event of a failure of a single active component (i.e., a blower) if the initial concentration is below three percent. After a blower failure is detected, such as through reduced flow, the TSV Reactivity Protection System (TRPS) would trip the TSV and neutron driver. A peak hydrogen concentration of 3.9 percent is estimated to occur in the case of a failure of a single active component (blower).

The hydrogen recombiner should be capable of preventing a hydrogen deflagration or detonation. The system will alert the operator of high hydrogen concentration if it reaches 2.5% by volume. Should the recombiner fail to prevent the rise of hydrogen concentration, the neutron driver will be shut down when the concentration reaches 3%. 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 blower failure. As long as sensors accurately capture the highest hydrogen concentration, both the alarm and the trip set-points would correspond to hydrogen concentrations below the upward propagation flammability limit in steam-saturated air of 4.1% listed in NUREG/CR-2726: "Light Water Reactor Hydrogen Manual". The system design pressure has not yet been specified but it will be designed to withstand system pressures expected during credible TSV power fluctuations and hydrogen deflagrations. The applicant committed to perform calculations during detailed design that will ensure there is sufficient margin to deflagration limits. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE's FSAR.

SHINE PSAR, Table 4a2.8-1, "TSV Off-Gas System Major Components," states that the condenser in the TSV off-gas condenser has a greater than 15 percent heat transfer margin. Since vapor pressure of water changes rapidly with temperature in the vicinity of 140 degrees F, for example, increasing the water temperature from 140 degrees F to 150 degrees F increases the vapor pressure by approximately 33 percent, the staff was concerned that non condensable gas can significantly degrade the condensation efficiency in comparison to the condensation of pure steam.

Therefore, in RAI 4a2.8-4 (Reference 14), the staff asked the applicant to provide the TSV and off-gas system operating conditions and assumptions used to calculate the 15 percent margin.

In response to RAI 4a2.8-4 (Reference 21), the applicant provided the TSV operating envelope and TOGS design assumptions for the gas leaving the TSV headspace during normal operation. The applicant stated, in part, that:

> [An] analysis of the TSV off-gas condenser heat transfer capabilities will be performed during the final design of the system. The condenser analysis will document the inputs and assumptions to the design of the TSV off-gas condenser, including consideration for bounding operating pressures and temperatures, corresponding steam vapor pressure, expected non-condensable gas concentrations, the impact on condenser performance, and operational degradation during the life of the condenser. The required TSV off-gas condenser specifications will be determined based on the bounding inputs and conservative assumptions. Then, an additional 15 percent design margin will be applied to the heat transfer area.

The staff will confirm that the final design provides adequate margin for the design basis during the evaluation of SHINE’s FSAR.

SHINE PSAR Section 4a2.8.5 states that a pressure safety valve is connected to the TOGS piping to passively prevent an over pressurization within the PSB, which may cause structural damage to the IU. Since the TOGS system contains radioactive fission products, in RAI 4a2.8-5, the staff asked the applicant to provide information indicating whether the relief valve discharge passes through a system capable of filtering or scrubbing out radioactive fission products and to provide a description of such a system if it exists.

In response to RAI 4a2.8-5 (Reference 21), the applicant stated, in part, that:

> [it] plans on connecting the pressure safety valve connected to the TOGS piping to the Noble Gas Removal System (NGRS). Final design of the NGRS will ensure the system contains a relief volume capable of receiving gas from TOGS in the event of an over-pressurization. Relief gases in the NGRS will be sampled and held for decay. Upon completion of an appropriate decay period, the gases in the NGRS will again be analyzed for radioactivity, and released to the Process Vessel Vent System (PVVS). In the PVVS, the off-gas is mixed with other process vessel exhaust gases, scrubbed through an acid-gas scrubber (caustic scrub solution), and vented to RVZ1, and exhausted out the facility stack following high efficiency particulate air (HEPA) and charcoal filtration. This process will ensure that the radioactive release and dose requirements of 10 CFR 20 are met.

The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE’s FSAR.

4a.4.8.1 Gas Management System Findings

The staff finds that the preliminary design of the SHINE gas management system, as described in SHINE PSAR Section 4a2.8, is sufficient and meets the applicable regulatory requirements and guidance to support the issuance of a construction permit in accordance with 10 CFR 50.35. Further technical or design information required to complete the safety analysis may reasonably be left for later consideration. The staff will confirm that the final design conforms to this design basis during the evaluation of SHINE’s FSAR.

4a.4.9 Probable Subjects of Technical Specifications

In accordance with 10 CFR 50.34(a)(5), the staff evaluated the sufficiency of the applicant's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications for the SHINE IU, with special attention given to those items which may significantly influence the final design.

Based on the information provided in Table 14a2-1 of the SHINE PSAR, the staff finds that identification and justification of the proposed LCOs for the Gas Management System is sufficient and meets the applicable regulatory requirements to support the issuance of a construction permit in accordance with 10 CFR 50.35. A complete evaluation of technical specifications, LCOs, and surveillance requirements will be performed during the review of SHINE's operating license application.

4a.5 Summary and Conclusions

As described in SHINE PSAR Section 4a2.1, the IU is an accelerator-driven subcritical operating assembly 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 summary and conclusions provided below apply to the eight IUs that are part of SHINE's IF.

The staff evaluated the descriptions and discussions of SHINE's IUs, as described in SHINE PSAR Section 4a2 and supplemented by the applicant's responses to RAIs, and finds that the preliminary design of SHINE's IU, including the principle design criteria, design bases, and information relative to materials of construction, general arrangements, provides reasonable assurance that the final design will conform to the design basis and meets all applicable regulatory requirements and acceptance criteria in or referenced in ISG Augmenting NUREG-1537. The staff further notes that the IUs are designed to operate with a minimum heat load during normal operation, which would promptly lessen by at least an order of magnitude following IU shutdown. This, coupled with the absence of long-lived fission product build-up following shutdown, indicates that operation of this facility would pose a minimal risk to the health and safety of the public.

On the basis of these findings, the staff has made the following conclusions to support the issuance of a construction permit in accordance with 10 CFR 50.35:

(1) SHINE has described the proposed design of the IU, including, but not limited, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public;
(2) Further technical or design information required to compete the safety analysis of the IU may be reasonably left for later consideration in the FSAR;
(3) There is reasonable assurance that the proposed facility can be constructed at the proposed location without undue risk to the health and safety of the public.

4b Radioisotope Production Facility

SER Section 4b, "Radioisotope Production Facility," provides an evaluation of the preliminary design of SHINE's RPF as presented in SHINE PSAR Section 4b, "Radioisotope Production Facility Description."

4b.1 Areas of Review

The staff reviewed SHINE PSAR Section 4b against applicable regulatory requirements using appropriate regulatory guidance and standards to assess the sufficiency of the preliminary design and performance of SHINE's RPF systems. As part of this review, the staff evaluated descriptions and discussions of SHINE's RPF, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations. The preliminary design of SHINE's RPF was evaluated to ensure the sufficiency of principle design criteria; design bases; and information relative to materials of construction, general arrangement, and approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design basis. In addition, the staff reviewed SHINE's identification and justification for the selection of those variables, conditions, or other items which are determined to be probable subjects of technical specifications for the facility, with special attention given to those items which may significantly influence the final design.

Areas of review for this section included the facility and process description, the radioisotope production facility biological shield, the radioisotope extraction system, and the special nuclear material processing and storage.

4b.2 Summary of Application

The summary provided in SER Section 4a.2, "Summary of Application," applies to both the IUs and the RPF.

4b.3 Regulatory Basis and Acceptance Criteria

The regulatory basis and acceptance criterial provided in SER Section 4a.3, "Regulatory Basis and Acceptance Criteria," applies to both the SHINE IF and RPF.

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

The staff performed a section-by-section evaluation of the technical information presented in SHINE PSAR Section 4b to assess the sufficiency of the preliminary design and performance of SHINE's RPF in support of the issuance of a construction permit, in accordance with 10 CFR 50.35(a). The sufficiency of the preliminary design and performance of SHINE's RPF is demonstrated by compliance with applicable regulatory requirements, guidance, and acceptance criteria, as discussed in Section 4a.3, "Regulatory Basis and Acceptance Criteria," of this SER. The results of this section-by-section technical evaluation are described in SER Section 4b.5, "Summary and Conclusion."

For the purposes of issuing a CP, the preliminary design of the SHINE RPF may be adequately described at a functional or conceptual level. The staff evaluated the sufficiency of the preliminary design of the SHINE RPF based on the applicant's design methodology and ability to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety. As such, the staff's evaluation of the preliminary design of SHINE's RPF does not constitute approval of the safety of any design feature or specification. Such approval will be made following the evaluation of the final design of SHINE's RPF, as described in the FSAR, as part of SHINE's operating license application.

4b.4.1 Facility and Process Description

The staff evaluated the sufficiency of SHINE's facility and process description of its RPF, as described in SHINE PSAR 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.

Section 4b.1, "Facility and Process Description," of SHINE's PSAR 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 systems and components are presented in sufficient detail to allow a clear understanding and to ensure that the RPF 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 are provided to allow a clear and general understanding of the physical RPF features and of the processes involved. The primary function of the facility is to extract, purify, package, and ship medical isotopes. The primary fission product barrier in the RPF consists of vessels and associated piping that contains the irradiated special nuclear material (SNM) and fission products (in solid, liquid or gaseous form) during the separation process.

The summary includes the names, amounts, and chemical and physical forms of the SNM that will be in process. The SHINE PSAR includes a list of byproduct materials (identity and amounts) in the RPF process solutions, finished products, and wastes from the process.

SHINE PSAR also includes a detailed description of the design and construction of the equipment that will be used while processing SNM outside the IF. It includes enough detail to identify materials that may have moderating, reflecting, or other nuclear-reactive properties.

The summary describes the chemical and physical forms of SNM in process, including the maximum amounts of SNM in process in various building locations.

SHINE PSAR presents 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 (particularly fission products or transuranic elements) characterized by identity and concentration.

SHINE PSAR 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 staff evaluation of the criticality safety program is discussed in more detail in Section 6b.3 of this SER.

SHINE PSAR contains a description of the design basis and implementation of any hazardous chemical safety features of the RPF for establishing and maintaining a hazardous chemical safety program. The staff evaluation of the chemical safety program is discussed in more detail in Section 13b.2 of this SER.

Based on the information provided in Section 4b.1 of the SHINE PSAR, the staff finds that the summary description of the facility and process of SHINE's RPF meets the applicable regulatory requirements and acceptance criteria of ISG Augmenting NUREG-1537 in support of the issuance of a construction permit in accordance with 10 CFR 50.35.

4b.4.2 Radioisotope Production Facility Biological Shield

The staff evaluated the sufficiency of the SHINE's RPF biological shield, as described in SHINE PSAR Section 4b.2, "Radioisotope Production Facility Biological Shield," using the guidance and acceptance criteria from Section 4b.2, "Processing Facility Biological Shield,'' of the ISG Augmenting NUREG-1537, Parts 1 and 2.

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 radioisotope production facility receives the irradiated target solution from the IU cell and distributes the target solution to various downstream processes. The target solution has a fission product activity that is defined in SHINE PSAR Chapter 11. The major areas outside of the IU cell that the target solution and by-product material occupy are as follows:

- Supercell (for molybdenum [Mo] extraction, purification, and packaging)
- Process tanks
- Pipe chases
- Waste processing cells
- UREX cell
- Thermal denitration (TDN) cell
- Pump room hot cell
- PVVS cell
- NGRS shielded cell

The RPF biological shields are provided to ensure that the projected radiation dose rates and accumulated doses in occupied areas do not exceed the limits of 10 CFR Part 20 and the guidelines of the facility ALARA program discussed in Chapter 11 of the SHINE PSAR.

All materials used for biological shielding meet or exceed the requirements of ANSI/ANS-6.4.2-2006, "Specification for Radiation Shielding Materials" (ANSI/ANS 2006b). The design and construction of the concrete portions of the RPF biological shield conforms to NRC Regulatory Guide 1.69, Revision 1 (Reference 37).

The biological shield requires a number of penetrations, inserts, and other features where the bulk shielding materials are reduced in thickness, or where the materials used in the penetration are less dense than the surrounding bulk material. Each penetration is designed with well-demonstrated techniques of non-linear paths, supplemental shielding, location in areas of low-incident radiation, and other methods to reduce streaming and leakage to ensure 10 CFR Part 20 limits are met.

Supports and structures ensure biological shield integrity, and quality control methods will ensure that fabrication and construction of the shield meet the design criteria.

SHINE PSAR Section 4b.2.2, "Biological Shield Design Basis," describes the shield design, which includes a detailed description of the design and construction of the RPF biological shield. The shielding design basis, including calculations that were used to prescribe the required form and substance of the shield, are provided. The shield design also describes the functional design of the biological shield, showing entry and exit facilities for products, wastes, process equipment, and operating staff.

SHINE PSAR Section 9a.2.1.1, “Radiologically Controlled Area Ventilation System,” includes a detailed description of the ventilation system for the biological shield structure, including (1) the design basis and function; (2) the design and location of vent ducting, filters, and fans; (3) details on vent system operating limits under both normal and emergency operating conditions; and (4) the design basis and function of all filtering and sequestration systems provided to control release of particulate and gaseous airborne radioactive contaminants to the environment under normal and emergency operating conditions. The RPF hot cells are ventilated with systems that are independent of the occupied zone ventilations. RPF hot cells are isolated from the building heating, ventilation, and air conditioning (HVAC) system upon detection of a leak, to prevent the spread of contamination.

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 applicable radiation exposure limits prescribed in 10 CFR Part 20 for the protection of the staff and the public are identified in SHINE PSAR Section 4b.2, and will be included in the technical specifications that will be provided in the FSAR Chapter 14.

The staff determined that the biological shield analysis in the SHINE PSAR offers reasonable assurance that the shield designs will limit exposures from the RPF sources of radiation so as not to exceed the limits of 10 CFR Part 20 and the guidelines of the facility ALARA program. The design offers reasonable assurance that the shield can be successfully installed with no radiation streaming or other leakage that would exceed the limits of 10 CFR Part 20 and the guidelines of the facility ALARA program. RPF components are sufficiently shielded to avoid significant radiation-related degradation or malfunction. Limiting conditions for operation and surveillance requirements for the shield will be included in technical specifications to be provided in Chapter 14 of the FSAR.

Based on the information provided in Section 4b.2 of the SHINE PSAR, the staff finds that the description of the biological shield of SHINE’s RPF meets the applicable regulatory requirements and acceptance criteria of ISG Augmenting NUREG-1537 in support of the issuance of a construction permit in accordance with 10 CFR 50.35.

4b.4.3 Radioisotope Extraction System

The staff evaluated the sufficiency of the SHINE’s RPF Radioisotope Extraction System, as described in SHINE PSAR 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.

Section 4b.3 of the SHINE PSAR provides the design and detailed description of the MEPS. SHINE PSAR Section 4b.3 provides a complete description, including diagrams and drawings, in sufficient detail to give a clear understanding of the extraction and purification process and how the process can be performed safely within regulatory limits.

SHINE’s PSAR provides the following processing details about 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 (proprietary) volumes in process and (proprietary) radioactive inventory in process.

- Criticality control features of the MEPS, provided through inherently safe geometrical design of MEPS equipment.
- Shielding and radiological protection features of the MEPS. The MEPS processes will be performed in shielded hot cells, which keeps worker exposure to radiation within the regulatory limits of 10 CFR 20.1201 and 10 CFR 20.1301. The processes are remotely, 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 to detect criticality events. Piping that contains potentially-radiological material is routed through shielded pipe chases to limit the worker exposure to radiation. Tanks within the MEPS are inside shielded hot cells, so additional tank shielding is not required.

The staff determined that the MEPS process descriptions in SHINE PSAR 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 this facility. 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. The criticality control measures provided throughout the MEPS process are in accordance with a double-contingency principle, and the MEPS provides suitable defense-in-depth for the contained processes. Sufficient engineered safety features have been developed that provide safe margins for all safety-related process variables.

Based on the information provided in Section 4b.3 of the SHINE PSAR, the staff finds that the description of the SHINE's Radioisotope Extraction System meets the applicable regulatory requirements and acceptance criteria of ISG Augmenting NUREG-1537 in support of the issuance of a construction permit in accordance with 10 CFR 50.35.

4b.4.4 Special Nuclear Material Processing and Storage

The staff evaluated the sufficiency of the SHINE's RPF Special Nuclear Material Processing and Storage, as described in SHINE PSAR Section 4b.4, "Special Nuclear Material Processing and Storage," using the guidance and acceptance criteria from Section 4b.4, "SNM Processing and Storage," of the ISG Augmenting NUREG-1537, Parts 1 and 2.

SHINE PSAR Section 4b.4 describes the processing components and procedures involved in handling, processing, and storing SNM. The processing and storage of SNM is conducted in the production facility building and the waste staging and shipping building. SNM is used throughout the radiologically controlled area (RCA) in both unirradiated and irradiated forms for the production of medical isotopes.

Mo-99 is extracted from the irradiated SNM in the MEPS. Following Mo-99 extraction, the processing of irradiated SNM is performed in the UNCS. When cleanup of solution is required, the UNCS converts spent target solution in the form of uranyl sulfate into uranyl nitrate, separates the uranium from fission products and transuranic isotopes in the UREX process, and recovers uranium in the form of uranium oxide in the TDN process. The uranium oxide is loaded into cans and then returned to the target solution preparation system (TSPS). Irradiated SNM is stored in criticality-safe tanks between irradiation cycles. SHINE PSAR Section 4b.4.1, "Processing of Irradiated Special Nuclear Material," discusses the processing of irradiated SNM in greater detail.

4b.4.4.1 Processing of Irradiated Special Nuclear Material

Table 4b.4-1, "Estimated RPF Special Nuclear Material Inventory," of the non-public version of SHINE PSAR Chapter 4, specifies the chemical form, physical form, and inventory in pounds and kilograms. This information is not public because it is security-related information. Tables 4b.4-6 through 4b.4-11 list the physical and chemical properties of the recycled target solution, spent target solution, UREX feed, TDN feed, UREX raffinate, and TDN product.

SHINE PSAR Section 4b.4.1 presents a summary description of the processes. Figures 4b.4-1 (proprietary), 4b.4-2, and 4b.4-3 present process flow diagrams of the uranyl nitrate preparation, uranium extraction, and TDN processes, respectively. This information includes data on expected levels of radioactivity, broken down by radionuclide (particularly volatile and long-lived fission products and transuranic elements). The radionuclide inventory is projected with decay time and tabulated at various times throughout the process. The description identifies points in the process where major separations are performed and describes the pathways of the separated radionuclides and other constituents.

SHINE PSAR Section 4b.4.1, along with Figures 4b.3-001 through 4b.4-007, provides a clear description of the process systems and components to allow a good understanding that the facility can be operated safely within regulatory limits. The processing materials are compatible with the process material contained 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 PSAR Section 4b.4.1.3 states that the UNCS prevents inadvertent criticality through the inherently-safe design of equipment that handles the irradiated SNM. A detailed description of the Criticality Safety Program is provided in SHINE PSAR Section 6b.3, "Nuclear Criticality Control."

SHINE PSAR Section 4b.4.1.2.2, "Hazardous Material," and Table 4b.4-12, "UNCS Hazardous Chemicals Inventory," identify hazardous chemicals that are used in the UNCS process. SHINE will have chemical inventory controls including separation of chemicals based on the potential for exothermic reactions. These controls, in addition to procedures controlling the processing of irradiated SNM, will include measures to prevent accidents. These procedures and controls will be described in the FSAR.

All of the essential physical and operational features of the irradiated SNM processing system that are required to prevent the release of radioactive material and to maintain radiation levels below applicable radiation exposure limits prescribed in 10 CFR Part 20, for the protection of the staff and the public, will be identified and included in the technical specifications in FSAR Chapter 14.

The staff determined that the process descriptions in SHINE PSAR Section 4b.4.1, together with the included tables and figures, provide a detailed account of the SNM in process along with fission-product radioactivity. The process descriptions for the uranyl nitrate preparation, UREX, and TND processes are sufficient to provide a clear understanding that these operations can be conducted safely in the RPF.

The staff determined that the UNCS processing facilities and apparatus have been 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.

The staff determined that the criticality control measures provided are in accordance with double-contingency principle, and the UNCS processing facility provides suitable defense-in-depth for the contained processes.

4b.4.2 Processing of Unirradiated Special Nuclear Material

Unirradiated SNM will be received in the form of uranium metal. Shipments of SNM will be received at the facility in solid form from a Department of Energy supplier. The shipments will consist of uranium metal enriched to 19.75 ± 0.2 percent U-235. The SNM will be manually transported in approved transport containers and stored criticality-safe in those containers in accordance with packaging limitations for use. The approved transport container is an NRC-licensed Type B shipping package. The SNM will be manually transferred to the uranium metal receipt area and removed from the transport containers and stored in uranium metal storage cans in criticality-safe configuration within the uranium metal storage rack. During the receipt process the uranium metal receipt inspections will be performed.

The uranium metal will be dissolved in nitric acid within the uranium metal dissolution tank (1-TSPS-02T) to provide makeup solution for uranium losses within the process. Once dissolution is complete the uranyl nitrate solution will be transferred to the recycle uranyl nitrate hold tank (1-UNCS-06T) for further processing and conversion to uranium oxide by the thermal denitrator (1-UNCS-08T). The uranium oxide produced from the dissolution of unirradiated uranium metal will be stored in uranium oxide storage cans in criticality-safe configuration within the uranium oxide storage rack in the uranium oxide storage area. Unirradiated SNM in the form of uranium oxide may be received for initial startup and recharging and will be stored in uranium oxide storage cans in criticality-safe configuration within the uranium oxide storage rack in the uranium oxide storage area. Uranium oxide will be stored for future production of uranyl sulfate target solution.

SHINE PSAR Sections 4b.4.2.2, “Uranium Metal Receipt,” through 4b.4.2.5, “Uranium Oxide Storage,” 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 form and chemical form of the SNM involved in each operation, and enough detail to enable development and analysis of potential accident sequences in SHINE PSAR Chapter 13.

SHINE PSAR Section 4b.4.2.6, “Unirradiated SNM Related Equipment,” describes process equipment associated with processing unirradiated SNM. System components are criticality-safe by design. The target solution hold tank glovebox, uranium receipt ventilation hood, and TDN interface glovebox will be designed and fabricated in accordance with American Glovebox Society code AGS-G00-2007, “Guideline for Gloveboxes,” 2007. Nominal sizes and specifications of tanks, uranium metal storage rack, uranium oxide storage rack, uranium metal storage can, and uranium oxide storage can are provided in the proprietary version of SHINE PSAR Chapter 4.

All of 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 prescribed in 10 CFR Part 20, for the protection of the staff and the public, will be identified and included in the technical specifications in FSAR Chapter 14.

The staff determined that process descriptions in SHINE PSAR Section 4b.4 provide a detailed account of the SNM in process. Each operation with 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 apparatus have been described in sufficient detail to provide confidence that the SNM can be controlled throughout the process so that the health and safety of the public will be protected. The criticality control measures provided are in accordance with a double-contingency principle and the processing facility provides suitable defense-in-depth for the contained processes.

Based on the information provided in Section 4b.4 of the SHINE PSAR, the staff finds that the summary description of SHINE's Special Nuclear Material Processing and Storage meets the applicable regulatory requirements and acceptance criteria of ISG Augmenting NUREG-1537 in support of the issuance of a construction permit in accordance with 10 CFR 50.35.

4b.5 Summary and Conclusions

The staff evaluated the descriptions and discussions of SHINE's RPF, as described in SHINE PSAR Section 4b, and finds that the preliminary design of SHINE's RPF, including the principle design criteria, design bases, and information relative to materials of construction, general arrangements, provides reasonable assurance that the final design will conform to the design basis and meets all applicable regulatory requirements and acceptance criteria in or referenced in ISG Augmenting NUREG-1537.

On the basis of these findings, the staff has made the following conclusions to support the issuance of a construction permit in accordance with 10 CFR 50.35:

(1) SHINE has described the proposed design of the IU, including, but not limited, the principal architectural and engineering criteria for the design, and has identified the major features or components incorporated therein for the protection of the health and safety of the public;
(2) Further technical or design information required to compete the safety analysis of the IU may be reasonably left for later consideration in the FSAR;
(3) There is reasonable assurance that the proposed facility can be constructed at the proposed location without undue risk to the health and safety of the public.