5.0 COOLANT SYSTEMS

The principal purpose of cooling systems in the NWMI production facility is to safely remove decay heat from the radioisotope extraction process vessels and dissipate it to the environment under normal and accident conditions. Cooling systems, including auxiliary and subsystems, should be shown to safely remove and transfer heat to the environment from all significant heat sources identified in the Northwest Medical Isotopes, LLC (NWMI or the applicant) preliminary safety analysis report (PSAR). The design of the cooling systems is based on interdependent parameters, including thermal power level at the target irradiation site, transport and handling times after the end of irradiation (EOI) prior to receipt at the NWMI facility, type and form of special nuclear material (SNM), neutronic physics, and radiation shielding.

This chapter of the NWMI construction permit safety evaluation report (SER) describes the U.S. Nuclear Regulatory Commission (NRC) staff (the staff) technical review and evaluation of the preliminary design of the NWMI production facility cooling systems as presented in Chapter 5.0, "Coolant Systems," of the NWMI PSAR, Revision 3, as supplemented by the applicant's responses to requests for additional information (RAIs). As explained in SER Section 1.1.1, "Scope of Review," the NWMI construction permit application generally refers to the building that will house all activities, structures, systems, and components (SSCs) related to medical isotope production as its radioisotope production facility (RPF). The RPF consists of the production facility and the target fabrication area as discussed below. In this SER, the staff refers to the SSCs within the RPF associated with the activities that NWMI states it will conduct under a license for a Title 10 of the Code of Federal Regulations (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," production facility as "the NWMI production facility," or "the facility." In this SER, the staff refers to the SSCs within the RPF associated with the activities that NWMI states it will conduct under a separate 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material," license as "the target fabrication area." The staff reviewed the entire NWMI construction permit application to understand the anticipated interface between and impact on the NWMI production facility from the target fabrication area. However, the staff's findings and conclusions in this SER are limited to whether the NWMI production facility satisfies the 10 CFR Part 50 requirements for the issuance of a construction permit.

5.1 Areas of Review

NWMI PSAR Chapter 5.0 describes the cooling systems used to control the temperature of process solutions in the NWMI production facility. Portions of the cooling systems (i.e., one of the secondary coolant loops and the portion of the process chilled water loop, which serves that secondary coolant loop), which are also discussed in NWMI PSAR Chapter 5.0, are located in the NWMI target fabrication area. Such equipment in the target fabrication area is outside the scope of the staff's review in this SER, which is limited to the NWMI production facility, and is discussed in this SER with regard to its relationship to the cooling systems in the NWMI production facility.

The staff reviewed NWMI PSAR Chapter 5.0 against applicable regulatory requirements using appropriate regulatory guidance and standards to assess the sufficiency of the preliminary design of the NWMI production facility's cooling systems. As part of this review, the staff evaluated descriptions and discussions of the NWMI production facility's cooling systems, with special attention to design and operating characteristics, unusual or novel design features, thermal characterization of process vessels, and principal safety considerations. The preliminary design of the NWMI production facility's cooling systems was evaluated to ensure the sufficiency of principal design criteria, design bases, and information relative to maximum temperature and pressure to provide reasonable assurance that the final design will conform to the design bases. The staff also considered the preliminary analysis and evaluation of the design and performance of the SSCs of the NWMI production facility's cooling systems with the objective of assessing the risk to public health and safety resulting from operation of the facility. In addition, the staff reviewed NWMI's identification and justification for the selection of those variables, conditions, or other items, which are determined to be probable subjects of technical specifications (TSs) for the facility, with special attention given to those items which may significantly influence the final design. The staff documented its review of NWMI's probable subjects of TSs for the facility in Chapter 14.0, "Technical Specifications," of this SER. NWMI did not identify any specific probable subjects of TSs for SSCs of the NWMI production facility's cooling systems.

Because the NWMI production facility cooling systems do not influence operation of any reactor primary core cooling system, the NWMI production facility cooling systems are, according to NUREG-1537, Part 1 "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content," characterized as auxiliary cooling systems, rather than primary or secondary cooling systems. However, the PSAR refers to the NWMI production facility's and target fabrication area's large geometry and criticality-safe geometry cooling loops (which are, in turn, cooled by a process chilled water loop) as secondary coolant loops, and therefore this terminology is also used in this chapter of the SER to describe these cooling loops.

Areas of review for this chapter included the irradiated target design basis (i.e., the amount of heat produced by the irradiated targets), vessels considered for thermal characterization, heat load and thermal flux, maximum vessel temperature and pressure estimates, potential impact of overcooling process solutions, and potential impact on the gas management system. Within these review areas, the staff assessed the following capabilities of the NWMI production facility's cooling systems:

- The capability of the secondary coolant loops to remove decay heat during normal operation and possible accident conditions, and transfer such heat to the process chilled water system.

- The capability of the process chilled water system to provide controlled heat dissipation to the environment.

- The capability of the NWMI production facility's cooling systems to limit maximum temperature and pressure within the facility's vessels to prevent failure of process apparatus.

- The capability of the NWMI production facility's vessel configurations to prevent inadvertent criticality due to overcooling of process solutions.

- The capability of a failure of the NWMI production facility's cooling systems to impact the dose consequences of an inadvertent release of noble gases.

5.2 Summary of Application

As described in NWMI PSAR Chapter 5.0, chilled water is used as the cooling fluid to control the temperature of process solutions in the NWMI production facility. The summary provided below describes the cooling systems that are used at the NWMI production facility, which are categorized as auxiliary cooling systems according to NUREG-1537, Part 1 and 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."

In NWMI PSAR Section 5.1, "Summary Description," NWMI states that chilled water is used as the cooling fluid to the NWMI production facility process vessels. A central process chilled-water loop is used to cool (1) one large geometry secondary loop in the hot cell, (2) one criticality-safe geometry secondary loop in the hot cell, and (3) one criticality-safe geometry secondary loop in the target fabrication area. The central process chilled-water loop relies on air-cooled chillers to maintain chilled water to various process equipment at no greater than 50 degrees Fahrenheit (10 degrees Celsius) during normal operation. The central process chilled-water loop cools the three secondary loops through plate-and-frame heat exchangers. Several NWMI production facility process demands require cooling at less than the freezing point of water. These demands are met with water-cooled refrigerant chiller units, cooled by the secondary chilled water loops.

5.2.1 Irradiated Target Design Basis

NWMI's irradiated target basis refers to the thermal load generated by irradiated targets. In NWMI PSAR Section 5.1.1, "Irradiated Target Basis," NWMI considers this thermal load in its evaluation of the cooling needed for NWMI production facility process vessels. NWMI PSAR Section 5.1.1 states that thermal characteristics of irradiated targets entering the NWMI production facility are based on preliminary calculations for targets irradiated at the Oregon State University TRIGA Reactor (OSTR). The OSTR preliminary calculations were extrapolated to estimate the heat load of a target irradiated at the University of Missouri – Columbia Research Reactor (MURR). The OSTR calculations resulted in an average power per OSTR target of approximately four times lower than the average power per MURR target. The MURR operation is based on irradiating 8 targets per week while the OSTR operation is based on irradiating 30 targets per week. Based on the combination of the number of targets, the reactor source, and the decay time for receipt of targets, the weekly heat load from radionuclide decay is estimated to be three times higher from MURR targets at 8 hours after EOI than compared to OSTR targets at 48 hours after EOI. Therefore, the MURR targets are used as the upper bound for evaluating the cooling requirements in the NWMI facility. These preliminary calculations are supported by the following NWMI PSAR figures:

- Figure 5-1, "Individual Irradiated Target Heat Generation"
- Figure 5-2, "Weekly Irradiated Target Receipt Heat Generation"

5.2.2 Vessels Considered for Thermal Characterization

NWMI PSAR Section 5.1.2, "Vessels Considered for Thermal Characterization," states that thermal characteristics of selected NWMI production facility process vessels are based on an evaluation in NWMI-2015-CALC-022, "Maximum Vessel Heat Load, Temperature, and Pressure Estimates." The evaluation did not include every process vessel; however, the selected vessels were considered sufficient to span the range of potential heat generation rates anticipated to be contained in process vessels. The evaluation included vessels that contain water-cooling jackets, vessels not projected to require cooling, and vessels used for transfer of solid material in air that are not influenced by the cooling water system, but are included in the evaluation to provide a more complete description of the vessel thermal characteristics and to indicate that some vessels will exist with relatively high surface temperatures during NWMI facility operation. The vessels selected for evaluation are shown in NWMI PSAR Table 5-1, “Vessels Selected to Describe Radioisotope Production Facility Thermal Characteristics.”

5.2.3 Heat Load and Thermal Flux

NWMI PSAR Section 5.1.3, “Heat Load and Thermal Flux,” states that the volumetric heat load contained by NWMI production facility process vessels varies throughout the system as radioisotopes decay, selected radioisotopes are separated, and solution compositions are adjusted by NWMI production facility operations. Thermal flux at the containment apparatus walls for process vessels is conservatively estimated by assuming only radial heat transfer, no radial temperature gradient, and neglecting heat loss from solution evaporation. The estimated volumetric heat load and radial thermal flux at the containment apparatus wall for several process vessels selected for evaluation indicate the range of conditions experienced as process solution is transferred through the NWMI production facility process equipment. These are shown in the following NWMI PSAR tables:

- Table 5-2, “Heat Load and Thermal Flux for Selected Water-Cooled Vessels”
- Table 5-3, “Heat Load and Thermal Flux for Selected Vessels without Water Cooling”

5.2.4 Maximum Vessel Temperature and Pressure Estimates

PSAR Section 5.1.4 states that an estimate of maximum vessel temperature and pressure is based on an overall heat transfer coefficient for a tank on legs containing water with an ambient air temperature of 35 °C (95° F). Vessel temperatures are estimated assuming no water-cooling system is active. Vessel pressures are estimated assuming each vessel is unvented and based on the vapor pressure of water at the estimated vessel temperature. The estimated maximum vessel temperature and pressure are shown in the following PSAR tables:

- Table 5-4, “Estimate of Maximum Temperature and Pressure in Water-Cooled Vessels”
- Table 5-5, “Estimate of Maximum Temperature and Pressure in Vessels without Water Cooling”

The maximum temperature and pressure that could be observed in process vessels without cooling system operation is listed in PSAR Table 5-4 for the molybdenum system feed tanks.

5.2.5 Potential Impact of Overcooling Process Solutions

NWMI PSAR Section 5.1.5, “Potential Impact of Overcooling Process Solutions,” states that overcooling of uranium-bearing process solutions has the potential to precipitate uranyl nitrate hexahydrate as a solid which effectively increases the uranium concentration contained by a process vessel and creates the potential for a nuclear criticality. Criticality evaluations are described in the following three documents:

- NWMI-2015-CALC-002, “Irradiated Target Low-Enriched Uranium Material Dissolution”
- NWMI-2015-CALC-005, “Target Fabrication Tanks, Wet Processes, and Storage”
- NWMI-2015-CALC-006, “Tank Hot Cell”

The results indicate that precipitation of uranyl nitrate hexahydrate as a solid results in conditions that remain below an upper subcritical limit of 0.94 for the configurations evaluated.

5.2.6 Potential Impact on Gas Management System

NWMI PSAR Section 5.1.6, “Potential Impact on Gas Management System,” states that the primary gas management system cooled section controls the decay time provided for noble gases (isotopes of krypton and xenon) by holdup in the dissolver offgas system.

5.3 Regulatory Basis and Acceptance Criteria

As previously stated and described in NWMI PSAR Chapter 5.0, chilled water is used as the cooling fluid to control the temperature of process solutions in the NWMI production facility. The NWMI production facility is at a separate site, independent from the reactors used to irradiate the targets. Therefore, the regulatory basis and acceptance criteria provided below apply to the NWMI production facility.

The staff reviewed NWMI PSAR Chapter 5.0 against applicable regulatory requirements, using appropriate regulatory guidance and standards, to assess the sufficiency of the preliminary design and performance of the NWMI production facility’s cooling systems for the issuance of a construction permit. In accordance with paragraph (a) of 10 CFR 50.35, “Issuance of construction permits,” a construction permit authorizing NWMI to proceed with construction of a production facility may be issued once the following findings have been made:

(1) NWMI has described the proposed design of its 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 and identified by NWMI, 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) taking into consideration the site criteria contained in 10 CFR Part 100, “Reactor Site Criteria,” the

proposed facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.

With respect to the last of these findings, the staff notes that the requirements of 10 CFR Part 100 are specific to nuclear power reactors and testing facilities, and therefore not applicable to the NWMI production facility. However, the staff evaluated the NWMI production facility's site-specific conditions using site criteria similar to 10 CFR Part 100, by using the guidance in NUREG-1537, Parts 1 and 2 (References 8 and 9), and the ISG Augmenting NUREG-1537, Parts 1 and 2 (References 10 and 11).

5.3.1 Applicable Regulatory Requirements

The applicable regulatory requirements for the evaluation of the NWMI production facility's cooling systems are as follows:

- 10 CFR 50.34, "Contents of applications; technical information," paragraph (a), "Preliminary safety analysis report."
- 10 CFR 50.40, "Common standards."
- 10 CFR Part 20, "Standards for Protection against Radiation."

5.3.2 Regulatory Guidance and Acceptance Criteria

The staff used its engineering judgment to determine the extent that established guidance and acceptance criteria were relevant to the review of NWMI's construction permit application, as much of this guidance was originally developed for completed designs of nuclear reactors. For example, in order to determine the acceptance criteria necessary for demonstrating compliance with the NRC's regulatory requirements in 10 CFR, the staff used:

- NUREG-1537, Part 1, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Format and Content," issued February 1996 (Reference 8).
- NUREG-1537, Part 2, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors, Standard Review Plan and Acceptance Criteria," issued February 1996 (Reference 9).
- "Final Interim Staff Guidance Augmenting NUREG-1537, Part 1, 'Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content,' for Licensing Radioisotope Production Facilities and Aqueous Homogeneous Reactors," dated October 17, 2012 (Reference 10).
- "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 11).

The ISG Augmenting NUREG-1537 updated and expanded the guidance, originally developed for non-power reactors, to address medical isotope production facilities. For example, whenever the word “reactor” appears in NUREG-1537, it can be understood to mean “radioisotope production facility,” as applicable. In addition, the ISG, at page vi, states that use of Integrated Safety Analysis methodologies as described in 10 CFR Part 70 and NUREG-1520, application of the radiological and chemical consequence likelihood criteria contained in the performance requirements of 10 CFR 70.61, “Performance requirements,” designation of items relied on for safety (IROFS), and establishment of management measures are acceptable ways of demonstrating adequate safety for a medical isotope production facility. The ISG also states that applicants may propose alternate accident analysis methodologies, alternate radiological and chemical consequence and likelihood criteria, alternate safety features and alternate methods of assuring the availability and reliability of safety features. The ISG notes that the use of the term “performance requirements,” when referring to 10 CFR Part 70, Subpart H, does not mean that the performance requirements in Subpart H are required for a radioisotope production facility license, only that their use may be found acceptable. NWMI used this ISG to inform the design of its facility and prepare its PSAR. The staff’s use of reactor-based guidance in its evaluation of the NWMI PSAR is consistent with the ISG Augmenting NUREG-1537.

As appropriate, additional guidance (e.g., NRC regulatory guides, Institute of Electrical and Electronics Engineers standards, American National Standards Institute/American Nuclear Society standards) has been used in the staff’s review of NWMI’s PSAR. The use of additional guidance is based on the technical judgment of the reviewer, as well as references in NUREG-1537, Parts 1 and 2; the ISG Augmenting NUREG-1537, Parts 1 and 2; and the NWMI PSAR. Additional guidance documents used to evaluate NWMI’s PSAR are provided as references in Appendix B, “References,” of this SER.

5.4 Review Procedures, Technical Evaluation, and Evaluation Findings

As described in NWMI PSAR Section 5.1, cooling water systems are used to control the temperature of process solutions in the NWMI production facility from process activities and the heat load resulting from radioactive decay of the fission product inventory. An air-cooled central process chilled water loop cools three secondary loops in the hot cell and target fabrication areas through plate-and-frame heat exchangers. Water-cooled refrigerant chiller packages are used to cool selected NWMI production facility processes to less than the freezing point of water. As stated in Section 5.1, “Areas of Review,” of this SER, the NWMI production facility cooling systems are not primary or secondary cooling systems, and the technical evaluation of the cooling systems focuses on the thermal characteristics of irradiated targets and process vessels and whether an adequate analysis has been provided to justify auxiliary cooling during the course of any part of the production process.

The staff evaluated the technical information presented in NWMI PSAR Chapter 5.0, as supplemented by the applicant’s responses to RAIs, to assess the sufficiency of the preliminary design and performance of the NWMI production facility’s cooling systems for the issuance of a construction permit, in accordance with 10 CFR Part 50. Additionally, the staff reviewed portions of the PSAR that describe vessels with and without water-cooling jackets and solid transfer containers without cooling jackets that may require cooling from chilled water. The staff also reviewed portions of the PSAR that describe the chilled water system. Sufficiency of the preliminary design and performance of the NWMI production facility’s cooling systems is determined by ensuring that the design and performance meet applicable regulatory requirements, guidance, and acceptance criteria, as discussed in Section 5.3, “Regulatory Basis and Acceptance Criteria," of this SER. A summary of the staff's technical evaluation is described in SER Section 5.5, "Summary and Conclusions."

For the purposes of issuing a construction permit, the preliminary design of the NWMI production facility's cooling systems may be adequately described at a functional or conceptual level. The staff evaluated the sufficiency of the preliminary design of the NWMI production facility's cooling systems 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 the NWMI production facility's cooling systems does not constitute approval of the safety of any design feature or specification. Such approval, if granted, would occur after an evaluation of the final design of the NWMI production facility's cooling systems as described in the FSAR submitted as part of NWMI's operating license (OL) application.

5.4.1 Summary Description

The staff evaluated the sufficiency of NWMI's summary description of its production facility's cooling systems, as described in NWMI PSAR Section 5.1, for the issuance of a construction permit using the guidance and acceptance criteria from Section 5.1, "Summary Description," of NUREG-1537, Parts 1 and 2, and Section 5b, "Radioisotope Production Facility Cooling Systems," of the ISG Augmenting NUREG-1537, Parts 1 and 2.

As stated, in part, in Section 5.1 of NUREG-1537, Part 2, the summary description of reactor cooling systems should include the type of primary coolant, type of primary coolant system, type of coolant flow in the primary and secondary cooling systems and the method of heat disposal to the environment, capability to provide sufficient heat removal for continuous operation at full licensed reactor power, and any special or facility-unique features. As stated, in part, in Section 5b of the ISG Augmenting NUREG-1537, Part 2, the applicant should provide a complete description of the design and operation of any required auxiliary cooling system.

NWMI PSAR Section 5.1 provides descriptions of the cooling water systems used to control the temperature of process solutions in the NWMI facility. As stated in NWMI PSAR Section 5.1, " … the RPF cooling system does not influence operation of a reactor primary core cooling system."

Based on its review, the staff finds that because the NWMI facility cooling system is independent of any reactor cooling system, Section 5.1 of NUREG-1537, Part 2, does not apply to the NWMI production facility. The staff also finds that NWMI described the design and operation of the process vessel cooling systems in its facility, including the capability of these systems to provide sufficient heat removal for the process vessels, consistent with Section 5b of the ISG Augmenting NUREG-1537, Part 2. Therefore, based on the information provided in NWMI PSAR Section 5.1, the staff concludes that the summary description of the NWMI production facility's cooling systems contains enough information for an overall understanding of the functions and relationships of the cooling systems to the preliminary design of the NWMI production facility, and satisfies the applicable acceptance criteria of NUREG-1537 and the ISG Augmenting NUREG-1537 for the issuance of a construction permit in accordance with 10 CFR Part 50.

5.4.2 Irradiated Target Design Basis

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.1 by reviewing the irradiated target processing capacity of the NWMI production facility, the operating power of the targets during irradiation in the off-site reactors, and the decay time allowed after the EOI in the off-site reactor before the separation process progresses using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the thermal characteristics of irradiated targets entering the NWMI production facility with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The ISG Augmenting NUREG-1537, Part 1, Section 5b states, in part, that "License applications for radioisotope production facilities should present an analysis of the thermal characteristics of the anticipated process that considers … [t]he operating power of the SNM during irradiation in the reactor [and] [t]he decay time allowed after the [EOI] in the reactor before the separation process progresses." As described in NWMI PSAR Section 5.1.1, the thermal characteristics of irradiated targets entering the NWMI production facility depend on the source reactor and decay time prior to receipt.

The applicant states that the heat load is based on preliminary calculations for targets irradiated at OSTR based on the OSTR operating power of 980 kilowatts thermal irradiating a target for a specified time period. The preliminary calculations resulted in an average power per target based on actinide and fission products produced during irradiation of a fresh uranium target containing a limited set of assumed impurities. The applicant extrapolated these preliminary calculations to estimate the heat load of a target irradiated at MURR. Assuming a similar irradiation time period, the extrapolation produces an average MURR target power of approximately four times higher per target.

The applicant states that due to the location of the NWMI production facility relative to the MURR and OSTR sites, the minimum decay time for receipt of targets after the EOI is estimated to be 8 hours for a MURR target and 48 hours for an OSTR target. Further, the applicant states that the combination of reactor source and minimum decay time produces estimated target heat loads of less than 200 watts (W) for a MURR irradiated target and less than 20 W for an OSTR irradiated target. In RAI 5.1-1 (Reference 13), the staff asked the applicant to provide additional detail on the 8-hour decay time allowed after the EOI of MURR targets including how the handling and transportation times have been determined and to demonstrate why the 8-hour decay time is conservative for evaluating the need for chilled water cooling.

In response to RAI 5.1-1 (Reference 31) and in PSAR Section 5.1.1, the applicant states that several material-handling steps must occur after the EOI within the reactor before a cask containing irradiated targets can be transported to the NWMI production facility. Examples include transfer of targets into the cask, removal of the loaded cask from the reactor pool, assembly of the cask lid, removal of water from the cask, drying the cask, performing the cask leak-check procedure, and cask decontamination and verification. The applicant states that at-reactor handling procedures are projected to require significantly longer than 8 hours for an individual cask. In addition, the applicant states that independent of the actual cask handling time required, the clock time for EOI of a target batch becomes a data point recorded on transfer papers, and a cask will not be unloaded until the minimum decay time after EOI used in safety evaluations has elapsed.

The applicant states that the number of irradiated targets received by the NWMI production facility in a single week varies with the source reactor. The MURR operation is based on irradiating 8 targets per week, while the OSTR operation is based on irradiating 30 targets per week. The combination of source reactor and number of targets per week results in an approximately equal total weekly heat load from radionuclide decay from either reactor as a function of decay time. However, the shorter decay time for MURR targets (8 hours) versus OSTR targets (48 hours) results in a higher weekly total heat load for MURR targets than OSTR targets. The applicant, therefore, concludes that the MURR operation would be used as a design basis upper bound for irradiated target receipt at the NWMI production facility. NWMI PSAR Section 4.1.2.1, “Process Design Basis,” states that, “The RPF is designed to have a nominal operational processing capability of one batch per week of up to 12 targets from University of Missouri Research Reactor (MURR)….” The nominal operational processing capability of 12 targets per week from MURR, as stated in NWMI PSAR Section 4.1.2.1, is greater than the 8 targets per week from MURR as stated in NWMI PSAR Section 5.1.1 for evaluating the need for auxiliary cooling and, therefore, in RAI 5.1-2 (Reference 13), the staff asked the applicant about this inconsistency.

In response to RAI 5.1-2 (Reference 31) and in PSAR Section 5.1.1, the applicant states that the target load per week described in PSAR Section 5.1.1 will be changed to 12 MURR targets per week in the FSAR included in its OL application. The applicant further states that the modification will include an update of NWMI-2015-CALC-022 with a more detailed analysis and revision of PSAR Section 5.1.1, Figure 5-2. The applicant states that the inconsistency identified is not expected to affect the thermal analysis in subsequent sections of NWMI PSAR Chapter 5.0 because the thermal load is characterized by radial heat transfer in a vessel and the uranium concentration of solutions held within vessels throughout the NWMI production facility. Additionally, the applicant states that increasing the number of targets processed during a given week increases the total liquid volume contained in geometrically favorable vessels (or liquid level height), but does not change the uranium concentration or radial thermal flux. The staff is tracking this issue in Appendix A, “Post Construction Permit Activities – Construction Permit Conditions and Final Safety Analysis Report Commitments,” of this SER.

The staff finds that with the information in the NWMI PSAR and its response to RAIs 5.1-1 and 5.1-2, discussed above, the applicant addressed the applicable acceptance criteria of the ISG Augmenting NUREG-1537, Part 2, Section 5b, by presenting an adequate analysis of the thermal characteristics of its anticipated process, and demonstrates an adequate design basis for a preliminary design. The staff will confirm that the final design conforms to this design basis during the evaluation of NWMI’s FSAR.

Although the preliminary calculations did not consider recycled uranium, a broader set of impurities, potential activation products, and MURR-specific radionuclide and thermal characteristics, based on its review, the staff finds that the description of the irradiated target basis contains a sufficient level of detail for an overall understanding of the functions and relationships of the NWMI production facility cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 5b, allowing the staff to make the following findings: (1) the irradiated target basis is adequate to determine the need for auxiliary cooling, (2) the preliminary calculations of irradiated target heat load based on OSTR operation and extrapolated to MURR operation are reasonable and sufficient, (3) the decay time design basis for MURR and OSTR irradiated targets is sufficient, and (4) the number of irradiated targets received by the NWMI production facility in a single week is sufficient for use in determining the need for auxiliary cooling.

Therefore, the staff concludes that the preliminary irradiated target basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.1 and supplemented by the applicant's responses to RAIs, is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. Further technical or design information required to complete the safety analysis can reasonably be left for later consideration, and will be provided in the FSAR. The staff will confirm that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.4.3 Vessels Considered for Thermal Characterization

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.2 by reviewing the design basis for vessel thermal characterization and the types of vessels selected for evaluation using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the thermal characteristics of process vessels within the NWMI production facility with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The ISG Augmenting NUREG-1537, Part 1, Section 5b states, in part, that "License applications for radioisotope production facilities should present an analysis of the thermal characteristics of the anticipated process that considers … [t]he volumetric heat load and the resultant thermal flux at heat transfer surfaces of the process containment apparatus throughout the process." As described in NWMI PSAR Section 5.1.2, a number of vessels were selected to describe the thermal characteristics; however, not every vessel was selected. The applicant states that the selected vessels were considered sufficient to span the range of potential heat generation rates anticipated to be contained in the process vessels.

The applicant selected three groups of vessels for thermal characterization including vessels that include water-cooling jackets, vessels not projected to require cooling, and vessels used for transfer or storage of solid material in air not influenced by the cooling water system. Uncooled vessels were included in the evaluation to provide a complete description of the vessel thermal characteristics. The applicant also states that the detailed design of the dissolver basket has not been completed; however, the thermal characterization calculations included calculations for the dissolver basket at the beginning and end of the dissolver cycle based on preliminary information. These calculations indicate that the dissolver basket has the potential to achieve relatively high equilibrium temperatures, but NWMI stated that the dissolver basket is not currently anticipated to be a completely enclosed vessel with the potential to build pressure on heating. The staff finds that these preliminary calculations are sufficient because they provide approximate values of dissolver basket temperatures that could be reached. The staff finds that the applicant's selected vessels are sufficient because these vessels are representative of the major process of the production facility.

Based on its review, the staff finds that the description of NWMI's selection of vessels for thermal characterization contains a sufficient level of detail for an overall understanding of the functions and relationships of the NWMI production facility cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 5b, allowing the staff to find that the vessels selected adequately represent the range of temperatures and pressures anticipated throughout the NWMI production facility.

Therefore, the staff concludes that the preliminary vessel thermal characterization design basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.2, is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. The staff will review the vessel thermal characterization design basis again during its review of the OL application. The staff will confirm that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.4.4 Heat Load and Thermal Flux

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.3 by reviewing the design basis for the volumetric heat load contained by process vessels using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the heat load and thermal flux within the NWMI production facility process vessels with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The ISG Augmenting NUREG-1537, Part 1, Section 5b states, in part, that "License applications for radioisotope production facilities should present an analysis of the thermal characteristics of the anticipated process that considers … [t]he volumetric heat load and the resultant thermal flux at heat transfer surfaces of the process containment apparatus throughout the process." As described in NWMI PSAR Section 5.1.3, the volumetric heat load contained by process vessels varies throughout the system as radioisotopes decay, selected radioisotopes are separated, and solution compositions are adjusted by the unit operations. The applicant states that the heat flux at the vessel boundary is estimated based on a simple steady-state heat balance considering only radial heat flow while neglecting axial heat flow and heat losses associated with evaporation of the liquid phase.

NWMI did not calculate the radial thermal flux for the dissolver at the start of the dissolution cycle in the PSAR, because NWMI did not consider its simplified evaluation methodology to be applicable. The staff finds that this calculation is not necessary for the issuance of a construction permit because it will not significantly alter the construction of the facility.

The applicant states that the heat load of process solutions prior to separating uranium from other radionuclides is characterized by the solution uranium concentration where the uranium concentration is estimated based on planned operating conditions and goal compositions during operation. Heat load in subsequent processes is estimated on a per-unit, uranium mass basis to approximate the impact of radionuclide separations. The applicant also states that three radionuclide decay times are used to describe the NWMI production facility thermal characteristics including: (1) a decay time of 8 hours after EOI for process solutions in the dissolver, molybdenum system feed tanks, and solution transferred into the impure uranium collection tanks, (2) a decay time of 3 weeks after EOI for process solutions at the end of the impure uranium collection tank storage period, solution in ion exchange feed tank one, solution transferred into the uranium decay tanks, and waste entering the high-dose waste concentrate collection tank, and (3) a decay time of 16 weeks after EOI for process solutions at the end of the storage period in the uranium decay tanks. The applicant states that the heat load in the high-dose waste vessels is based on accumulating waste from 16 weeks of operation even though current plans are based on accumulating waste for only 4 weeks.

Based on its review, the staff finds that the NWMI heat load and thermal flux analysis contains a sufficient level of detail for an overall understanding of the functions and relationships of the NWMI production facility cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of the ISG Augmenting NUREG-1537, Part 2, Section 5b, allowing the staff to make the following findings: (1) the design basis for calculating heat load and thermal flux is adequate to determine the need for auxiliary cooling, (2) the three radionuclide decay times used to describe the NWMI production facility thermal characteristics are sufficiently conservative to determine the need for auxiliary cooling, and (3) the 16 weeks of accumulating waste in the high-dose waste vessel is sufficiently conservative relative to the planned 4-week accumulation time period to bound the expected waste vessel heat load.

Therefore, the staff concludes that the preliminary vessel heat load and thermal flux design basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.3, is sufficient and meets the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. The staff will review the vessel heat load and thermal flux design basis again during its review of the OL application. The staff will confirm that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.4.5 Maximum Vessel Temperature and Pressure Estimates

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.4 by reviewing the design basis for the process vessel temperature and pressure calculations using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the maximum temperature and pressure within the NWMI production facility process vessels with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The ISG Augmenting NUREG-1537, Part 1, Section 5b states, in part, that "License applications for radioisotope production facilities should present an analysis of the thermal characteristics of the anticipated process that considers … [c]alculations of the resultant maximum temperature of material in process with the objective of determining the need for auxiliary cooling to maintain the temperature and pressure within the processing components at safe levels to prevent the failure of the process apparatus or the containment system." As described in NWMI PSAR Section 5.1.4, vessel temperatures are estimated assuming no water-cooling system is active and pressures are estimated assuming each vessel is unvented.

The applicant states that the preliminary temperature estimates assume that radial temperature variations within the generating heat material are not significant and that this assumption is questionable for containers of heat-generating solids. The applicant also states that the vapor pressure of water at the estimated vessel temperature is used to approximate the maximum pressure within the process vessels and that this method is conservative since the total vapor pressure of a solution is decreased by the addition of nitric acid or uranyl nitrate to the liquid phase. Based on this design basis, the maximum temperature and pressure that could be observed in NWMI production facility process vessels without operation of the coolant systems is listed in NWMI PSAR Table 5-4 for the molybdenum system feed tank. However, the design basis was not considered applicable to the dissolver tank at the beginning of the dissolver cycle because of the non-uniform distribution of heat-generating material. The staff finds that the calculation of maximum temperature and pressure for the dissolver tank at the beginning of the dissolver cycle is not necessary for the issuance of a construction permit, because it will not significantly alter the construction of the facility.

Based on its review, the staff finds that the description of the NWMI production facility's heat load and thermal flux design basis contains a sufficient level of detail for an overall understanding of the functions and relationships of the NWMI production facility cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 5b, allowing the staff to make the following findings: (1) the design basis for calculating maximum vessel temperature and pressure is adequate to determine the need for auxiliary cooling and (2) maximum temperature and pressure within the processing components are maintained at safe levels without the need for cooling.

Therefore, the staff concludes that the preliminary maximum temperature and pressure design basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.4, is sufficient to meet the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. The staff will review the maximum temperature and pressure design basis again during its review of the OL application. The staff will confirm that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.4.6 Potential Impact of Overcooling Process Solutions

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.5, "Potential Impact of Overcooling Process Solutions," by reviewing the design basis for evaluating the impact of uranium precipitation upset conditions using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the uranium precipitation calculations with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The acceptance criteria in the ISG Augmenting NUREG-1537, Part 2, Section 5b, states, in part, that "adequate precautionary measures are in place to prevent detrimental changes to the physical or chemical characteristics of the SNM solution. As an example, precautions against exceeding the solubility limits of the SNM in solution due to overcooling should be in place." As described in NWMI PSAR Section 5.1.5, overcooling of uranium-bearing process solutions has the potential to precipitate uranyl nitrate hexahydrate as a solid that effectively increases the uranium concentration potentially resulting in a nuclear criticality.

The applicant states that the impact of uranium precipitation upset conditions on nuclear criticality was evaluated by interspersing selected tanks containing a specified uranium concentration among the vessels containing uranium at a conservative nominal process concentration. The results of adding this additional uranium to the NWMI production facility process vessels to simulate uranyl nitrate hexahydrate precipitation indicates that the precipitation upset conditions remain below an upper subcritical limit of 0.92 and pose no nuclear criticality hazard for the current NWMI production facility equipment configuration.

Based on its review, the staff finds that the description of the potential impact of overcooling process solutions contains a sufficient level of detail for an overall understanding of the functions and relationships of the NWMI production facility cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 5b, allowing the staff to make the following findings: (1) the design basis for calculating the potential impact of overcooling process solutions is adequate to determine the potential threat of an inadvertent nuclear criticality, and (2) overcooling of process solutions does not pose a nuclear criticality hazard for the current NWMI production facility equipment configuration that could impact the occupational safety and protection of the public and environment.

Therefore, the staff concludes that the overcooling design basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.5, is sufficient to meet the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. The staff will review the overcooling design basis again during its review of the OL application. The staff will specifically confirm these criticality calculations and that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.4.7 Potential Impact on Gas Management System

The staff evaluated the sufficiency of the analysis supporting the preliminary design of the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.6, "Potential Impact on Gas Management System," by reviewing the design basis for evaluating the potential impact of coolant systems on the gas management system using the guidance and acceptance criteria from Section 5b of the ISG Augmenting NUREG-1537, Parts 1 and 2.

Consistent with the review procedures of the ISG Augmenting NUREG-1537, Part 2, Section 5b, the staff compared the bounding release of noble gases from the dissolver offgas system with the cooling system design basis, as presented in NWMI PSAR Chapter 5.0.

The acceptance criteria in the ISG Augmenting NUREG-1537, Part 2, Section 5b, states, in part, that "The acceptance criteria specified in NUREG-1537, Part 2, Section 5a2.7, may be used as they would apply to any required radioisotope processing cooling system." The acceptance criteria in the ISG Augmenting NUREG-1537, Part 2, Section 5a2.7, states, in part, that "The system should not cause radiation exposures or release of radioactivity to the environment that exceed the requirements of 10 CFR Part 20 and the facility's [as low as is reasonably achievable] ALARA program guidelines." As described in NWMI PSAR Section 5.1.6, coolant system operation has the potential to impact the performance of the gas management system cooled sections since the cooled sections of the gas management system control the decay time provided for noble gases by holdup in the dissolver offgas system. However, NWMI stated that based on its dose analyses in NWMI PSAR Chapter 13.0, "Accident Analysis," the dose consequences of bounding noble gas releases would be small, and consequently NWMI does not consider the cooling water system to be an IROFS based on the potential impact to the gas management systems.

Based on its review, the staff finds that the description of the NWMI production facility's potential impact on the gas management system contains a sufficient level of detail for an overall understanding of the functions and relationships of the cooling system to the preliminary design of the NWMI production facility and satisfies the applicable acceptance criteria of NUREG-1537, Part 2, Section 5b, allowing the staff to make the following findings: (1) the design basis for calculating the dose consequences from a bounding release of noble gases is adequate to determine the potential threat of an inadvertent discharge of noble gases, and (2) the coolant system is not an IROFS based on the impact of a coolant system failure on the gas management system.

Therefore, the staff concludes that the design basis for the NWMI production facility's chilled water system, as described in NWMI PSAR Section 5.1.6, is sufficient to meet the applicable regulatory requirements and guidance for the issuance of a construction permit in accordance with 10 CFR Part 50. The staff will review the chilled water system's potential impact on the gas management system again during its review of the operating license application. The staff will confirm that all aspects of the final design conform to the design basis during the evaluation of NWMI's FSAR.

5.5 <u>Summary and Conclusions</u>

As described in NWMI PSAR Chapter 5.0, chilled water is used as the cooling fluid to control the temperature of process solutions in the NWMI production facility. The summary and conclusions provided below apply to the NWMI production facility's cooling systems.

The staff evaluated the descriptions and discussions of the NWMI production facility's cooling systems as described in NWMI PSAR Chapter 5.0 and supplemented by the applicant's responses to RAIs, and finds that the preliminary design of the cooling systems, including the principal design criteria, design bases, and information relative to materials of construction, general arrangement, and approximate dimensions: (1) provides reasonable assurance that the final design will conform to the design basis, and (2) meets all applicable regulatory requirements and acceptance criteria in or referenced in NUREG-1537 and the ISG Augmenting NUREG-1537. The staff further notes that the NWMI production facility is designed to operate with a minimal heat load during normal operation. This, coupled with the absence of long-lived fission product build-up, indicates that operation of the NWMI production facility would pose a minimal risk to the health and safety of the public.

Based on these findings, the staff concludes the following regarding the issuance of a construction permit in accordance with 10 CFR Part 50:

(1) NWMI has described the proposed design of the production facility cooling systems, including, but not limited to, the principal architectural and engineering criteria for the design, and has demonstrated that the cooling system is not an IROFS, and that the major features or components incorporated therein do not need to be functional 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 of the facility cooling systems and which can reasonably be left for later consideration, will be supplied in the FSAR.

(3) There is reasonable assurance that, taking into consideration the site criteria contained in 10 CFR Part 100, the proposed production facility can be constructed and operated at the proposed location without undue risk to the health and safety of the public.

(4) There is reasonable assurance: (i) that the construction of the NWMI facility will not endanger the health and safety of the public, and (ii) that construction activities can be conducted in compliance with the Commission's regulations.

(5) The issuance of a permit for the construction of the facility would not be inimical to the common defense and security or to the health and safety of the public.

(6) The preliminary design of the production facility cooling systems provides reasonable assurance that the applicant will comply with the regulations in 10 CFR Part 20 and that the health and safety of the public will not be endangered.