INL/MIS-23-73947-Revision-0

SPC-70646 Specification for Reactor Supplemental Shielding for Use in DOME

July 2023

Changing the World's Energy Future

Philip Lee Schoonover II

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

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Specification for Reactor Supplemental Shielding for Use in DOME

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CONTENTS

PART 1 GENERAL

A. NRIC is developing the Demonstration of Microreactor Experiments (DOME) test bed at the Idaho National Laboratory (INL) Materials and Fuels Complex (MFC): to allow for testing of advanced reactors in support of future licensing and commercial operations. One such need is a neutron and photon radiation shielding system to protect personnel and equipment from harsh neutron and photon fluxes during reactor operations and post shut down operations, disassembly, and decommissioning.

B. The reactor experiments planned for the NRIC DOME test bed are substantially different from traditional commercial nuclear reactors. These differences result in the need for supplemental shielding systems to meet dose rate and activation limits at MFC. One key difference in the leading round of reactors is the lack of large quantities of water in the reactor system. A second key difference is the lack of large amounts of concrete in the associated structures due to the compact size and potential mobility. Both differences result in a much lower level of inherent radiation shielding from the reactor.

C. This specification establishes the requirements for development of the reactor supplemental shielding design through preliminary and final design phases.

D. As some of the shield enclosure Structure, Systems, and Components (SSC) are identified as Safety Related, NQA-1 controls are required to complete the design scope defined herein. The lowest expected safety classification for the shield enclosure is Safety Significant, as this shielding will be required for the protection of personnel from high radiation fields.

E. NRIC has employed Digital Engineering tools and Systems Engineering process across its portfolio. Deliverables Shall be submitted in specified tools or in digital formats agreed by the Contractor.

PART 2 WORK INCLUDED

A. The Subcontractor Shall identify, analyze, and develop the optimal material, configuration, and cost of the shield enclosure required for reactor developers to use the NRIC DOME testbed. All materials used in the shielding design Shall be approved by the Contractor.

B. The Subcontractor Shall provide, in a phased approach, preliminary and final design of a shielding system that allows for the testing of advanced micro-reactors in the DOME testbed. After completion of the final design, the Contractor may at its sole discretion request from the Subcontractor a proposal to fabricate the reactor supplemental shielding to the Contractor-approved final design.

C. Preliminary Design (Phase 1): The Subcontractor Shall supply a preliminary design report consistent with the requirements of GDE-987. The Preliminary Design Report Shall be presented to the Contractor in an informal Preliminary Design Review (PDR) that may be held virtually, or in-person at the INL facility. The report Shall be submitted no less than 5 calendar days prior to the presentation. It is expected that the Subcontractor will consider the latest conceptual design of the reactor supplemental shielding in the development of the preliminary design. However, the Subcontractor Shall develop recommendations independently from the conceptual design. Innovative solutions are highly encouraged. The design report Shall include the following:

a. A proposed revised set of requirements (with applicable rationale) for developing the final design of the shielding system. This input will be used to ensure shielding system requirements are fully defined and can be validated.

b. A design verification matrix documenting how the preliminary design meets the reactor supplemental shielding requirements.
c. The Subcontractor Shall provide a 3D model of the system in PTC CREO format, or a Contractor approved alternate format.
d. Drawings, parametrically driven from the 3D models, with sufficient detail for obtaining quotes for fabrication of the shielding system.
e. A Monte Carlo N-Particle Transport (MCNP) model, including the input file for each material used, identifying anticipated dose rates using the shielding system for an operational reactor and a shutdown reactor. This analysis Shall identify additional requirements for mitigating dose rate impacts due to penetrations through the shield enclosure.
f. Structural assessment of the shielding system demonstrating the shielding enclosure will maintain its structural integrity when subjected to a seismic design category (SDC)-3 seismic event. Structural analysis to include anchorage of supplemental shield enclosure to the DOME containment operating floor. Structural analysis Shall also develop the in-structure seismic response spectra for equipment anchored to the shield enclosure at various coordinates and identify resonant frequencies for the shield enclosure.
g. Structural assessment demonstrating that the shielding system does not exceed DOME containment floor load limits.
h. Identification of applicable temperature requirements and fire rating for proposed materials.
i. Sizing calculations and equipment datasheets for major equipment needed for cooling the shield enclosure (e.g., pumps, heat exchangers, expansion tanks, fans, etc.).
j. Detailed thermal analysis that estimates the temperature of the shielding during steady state normal operating conditions and a transient decay heat condition after the reactor shuts down with no active cooling available (e.g., loss of power).
k. Design interfaces with the existing DOME test bed equipment for the cooling system. This is expected to include electrical and control systems for the shield cooling.
l. Should water be used for shielding (consistent with the latest conceptual shield design), it is expected that water level, leak detection, flow rates, and temperature monitoring will be required. An automatic reactor shutdown is expected to be required if significant leakage is identified through monitoring systems (e.g., low water level).
m. Cost estimate for the shielding system and load handling strategy that can be used with advanced micro reactors in the DOME testbed to manipulate sections or pieces of the shielding system.
n. Draft test matrix (validation plan) for the preliminary design that integrates design requirements with construction, installation, and commissioning.
o. The Subcontractor Shall provide a reliability and maintainability analysis of the proposed system, to include expected mean time between failures (MTBF) for mechanical and electrical equipment.
p. The Subcontractor Shall provide a Concept of Operations describing how the supplemental shielding system will be used during a typical reactor testing lifecycle.
q. The Subcontractor Shall provide a proposed schedule for completion of Phase 2 (Final Design).
r. The Subcontractor Shall provide a list of assumptions and unverified assumptions related to the system.

D. Final Design (Phase 2): The Subcontractor Shall supply a final design report consistent with the requirements of GDE-987. The Final Design Report Shall be presented to the Contractor in a Final Design Review (FDR) that may be held virtually, or in-person at an INL facility. The report Shall be submitted no less than 5 calendar days prior to the presentation. The design report Shall include the following:

a. A final set of requirements (with applicable rationale) for the shielding system, including interface requirements for experimenters.
b. A design verification matrix documenting how the final design meets the reactor supplemental shielding requirements.
c. The Subcontractor Shall provide a 3D model of the system in PTC CREO format, or a Contractor approved alternate format.
d. Drawings, parametrically driven from the 3D models, with sufficient detail for fabrication and assembly of the shielding system (i.e., full engineering definition, not necessarily a shop drawing).
e. An MCNP model, including the input file for each material used, demonstrating dose rate requirements are met using the shielding system, as well as calculated dose rate maps for an operational reactor and a shutdown reactor. This analysis Shall include expected penetrations through the shield enclosure as well as additional shielding needed to mitigate the dose rate impact due to these penetrations.
f. Structural analysis of the shielding system demonstrating the shielding enclosure will maintain its structural integrity when subjected to SDC-3 seismic event. Structural analysis to include anchorage of supplemental shield enclosure to the DOME containment operating floor. Structural analysis Shall also develop the in-structure seismic response spectra for equipment anchored to the shield enclosure at various coordinates and identify resonant frequencies for the shield enclosure.
g. Structural assessment demonstrating that the shielding system does not exceed DOME containment floor load limits.
h. Identification of applicable temperature requirements and fire rating for proposed materials.
i. Revised equipment sizing calculations and equipment datasheets for major equipment needed for cooling the shield enclosure (e.g., pumps, heat exchangers, expansion tanks, fans, etc.), as needed.
j. Detailed thermal analysis that demonstrates the temperature of the shielding during steady state normal operating conditions and a transient decay heat condition after the reactor shuts down with no active cooling available (e.g., loss of power).
k. Design interfaces with the existing DOME test bed equipment for the cooling system. This is expected to include electrical and control systems for the shield cooling.
l. Should water be used for shielding (consistent with the latest conceptual shield design), it is expected that water level, leak detection and dose rate monitoring systems will be required.
m. The Contractor will provide safety functions and safety classification of DOME shielding SSCs. It is expected, but necessarily required, that a water level or a dose rate monitoring system will be used to initiate an automatic reactor shutdown upon identification of a loss of shielding function.
n. A Class 3, or better, cost estimate for the shielding system, IAW DOE G 413.3-21A, 2018.
o. Relevant fabrication and construction specifications.
p. Installation and Test Plans.

q. The Subcontractor Shall provide a reliability and maintainability analysis of the proposed system, to include expected MTBF for mechanical and electrical equipment.

r. The Subcontractor Shall provide a list of key materials, components, or equipment with expected lead times exceeding 120 calendar days.

s. The Subcontractor Shall provide a Concept of Operations describing how the supplemental shielding system will be used during a typical reactor testing lifecycle.

t. The Subcontractor Shall provide a list of assumptions and unverified assumptions related to the system.

E. Option to Fabricate (Optional Phase 3): The Contractor may at its sole discretion request a proposal to fabricate the DOME Supplemental Shielding to the Contractor-approved final design.

PART 3 WORK NOT INCLUDED

A. Fabrication is reserved as an optional scope to be added after completion of the final design, if requested by the Contractor (INL/Battelle Energy Alliance). Installation of the DOME shield enclosure is not included as part of this specification.

PART 4 CONTRACTOR-PROVIDED MATERIALS, EQUIPMENT AND SERVICES

A. The Contractor will provide pertinent documentation generated through previous conceptual shield design iterations for use in the design efforts described in this specification.

B. The Contractor will provide a 3D model of the DOME containment structure.

PART 5 APPLICABLE CODES, PROCEDURES AND REFERENCES

5.01 CODES & STANDARDS:

A. ASME NQA-1-2008 / 1a-2009, Quality Assurance Requirements for Nuclear Facility Applications

B. STD-10011, Rev. 4, Drawing Requirements Standard

C. DOE-STD-1066-2016, Fire Protection

D. DOE STD-1020-2016, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities

E. DOE G 413.3-21A, 2018, Cost Estimate Guide

F. ASCE 43, 2005, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

G. STD-139, latest revision, INL Engineering Standards Manual

H. STD-142, latest revision, Nuclear Engineering Standards Manual

I. DOE-STD-1189-2016, Integration of Safety into the design process

5.02 REFERENCES:

A. GDE-987, latest edition (not yet issued), NRIC Design Review Criteria

B. Appendix H of ECAR-6327 (SGH Calculation 211676-CA-01, Rev. 0), EBR-II Containment Preliminary/Final Analysis and Design

C. COR-0006, Rev. 2, Demonstration of Microreactor Experiments (DOME) Code of Record

D. 1129-0298-RPT-001, latest edition (not yet issued), DOME Shield Conceptual Design

E. LWP-4503, Rev. 7, Supplier Evaluation and Commercial Grade Survey

PART 6 DESIGN REQUIREMENTS

A. Design requirements for the DOME shielding system are managed in DOORS (Dynamic Object-Oriented Requirements System), a requirements management tool. The shield enclosure design requirements are listed in Appendix A of this specification, along with their rationale and DOORS artifact number. The shielding design requirements will need to be expanded and revised, including derivation of system and component requirements, as the design matures. It is expected that this will be a collaborative effort between the Contractor and the Subcontractor. However, any changes to design requirements Shall be approved by the Contractor and incorporated into a revision of this specification prior to the issuance of a design report (preliminary or final) that demonstrates how each design requirement is met.

B. The Subcontractor Shall establish applicable Codes and Standards consistent with COR-0006, Demonstration of Microreactor Experiments (DOME) Code of Record.

C. Appendix A of this specification classifies the shield enclosure design requirements in the following categories:

a. Performance Requirements:
   i. Size, Configuration, and Handling
   ii. Electrical
   iii. Instrumentation and Controls
   iv. Mechanical
b. Operational Requirements:
   i. Radiological Controls
   ii. Operating Environment
c. Reliability Requirements
d. DOME Facility Requirements
   i. Structural
   ii. Environmental
   iii. Life Safety

PART 7 SUBMITTALS

A. General: This section specifies the administrative, technical, and quality requirements for submittals. Submittal requirements are tabulated on a Vendor Data Schedule (Form 431.14). The Subcontractor Shall allow for a minimum of two weeks for Contractor review of submittals and Shall advise the Contractor of any submittal that may be delayed, with the forecasted impact to the completion of the project, if any.

B. Engineering deliverables Shall not be marked as proprietary information.

C. Drawings: Each drawing submittal Shall be complete and Shall be accompanied by technical and performance data as necessary to fully support the information in the drawings, or cross referenced to such data contained in other submittals (e.g., calculations). Drawings Shall clearly identify safety class and safety significant components and Shall meet the requirements of STD-10011.

D. Calculations: Calculations Shall document design acceptability and limitations. Calculations Shall be approved by the Contractor.

E. Professional Engineer Seal: All final engineering deliverables Shall be signed and sealed by a professional engineer.

F. Test Procedures: Test and inspection procedures Shall include, as applicable: description of item or items involved, inspection or testing to be performed, a listing of testing agency and technical personnel to be used, description of equipment, components and facilities to be used, test and inspection prerequisites, test and inspection methods, test evaluations and acceptance criteria, safety precautions, sign-off requirements, methods for control and calibration of measuring and test equipment, proposed test record form, references to applicable portions of the Contract documents, and detailed procedures, methods, and criteria for evaluation and acceptance.

G. Operation & Maintenance(O&M) Manual: An O&M Manual Shall be the standard publication issued for the product by the Subcontractor and Shall contain component installation and maintenance instructions and limitations.

H. Commercial Grade Dedication: If the Subcontractor foresees that commercial grade dedication will be implemented as the primary acceptance method of safety class (SC) items, commercial grade dedication plan(s) Shall be submitted to the Contractor via the Vendor Data System, or a method mutually agreed upon by the Subcontractor and the Contractor. The commercial grade dedication plans, if needed, Shall describe the component's safety functions and the proposed test plan to demonstrate that each SSC can perform their safety function(s), per LWP-4503.

PART 8 QUALITY ASSURANCE

A. Quality Assurance Program:

1. The Subcontractor Shall have a quality assurance program that meets the requirements of ASME NQA-1-2008 / 1a-2009 Addenda. The quality assurance program used by the Subcontractor Shall be approved by the Contractor.
2. QA Program requirements Shall be implemented by the Subcontractor and flowed down to all lower tier subcontractors along with the applicable requirements of this specification.

B. Additional Quality Clauses/Instructions

1. The Subcontractor Shall be listed on the INL Qualified Supplier List (QSL) and capable of performing the scope of work included herein.
2. Any exceptions to the requirements of this specification or in procurement documents Shall be requested by the Subcontractor via Form 540.33, "Change Request," and Shall be approved by the Contractor.

PART 9 DELIVERY, STORAGE, AND PROTECTION

A. Not applicable, as this specification is limited to the design of the reactor supplemental shield enclosure.

Appendix A

Shield Enclosure Requirements, Rationale, and DOORS Artifact Numbers

This document was downloaded from a project requirements management database. Each requirement has an unique number in brackets [ ] to the left of the requirement text in lieu of sequential numbers to provide traceability back to the database. Information that is preliminary is indicated with curly brackets "{}". Acronyms used in this Appendix include:

DOME	Demonstration of Microreactor Experiments
GFCI	Ground Fault Circuit Interrupter
HRS	DOME Heat Removal System
MCC	Motor Control Center
RSS	Reactor Supplemental Shielding

A.1 Performance Requirements

A.1.1 Size, Configuration, and Handling

[16611] Component Size: All RSS components Shall be designed to fit through the DOME equipment hatch (15 ft. W x 17 ft. H clear opening).

Rationale: Maximum clear area through the DOME equipment hatch.

[15092] Reactor Handling: Provisions Shall be made for installing, removing, handling, and positioning a reactor module the size of an intermodal shipping container.

Rationale: The size of experiments utilizing the DOME is limited to intermodal shipping containers. The test bed is responsible for moving the experiment once received at the site.

[96808] RSS Lifting: A temporary lifting device Shall be used for all lifting activities.

Rationale: At this time, the dome containment does not have a functional permanent lifting device installed.

[96805] RSS Lifting and Rigging: RSS components that require movement Shall have engineered attachment points.

Rationale: This requirement supports safe load handling activities (lifting, rigging, jacking, sliding, etc.) by ensuring RSS components are designed with engineered features that are analyzed for the applicable load (weight, size, center of gravity, etc.). ASME BTH, Design of Below-the-Hook Lifting Devices, should be used where applicable.

[16616] RSS Component Weight: RSS components that require lifting for installation and removal Shall weigh less than {75} Tons.

Rationale: The weight of each component to be lifted is restricted by the capacity of the lifting device available for use in the lifting activity. At this time, the dome containment does not have a functional permanent crane installed.

[98030] RSS Removable Components: All RSS components (walls, floor, and roof shielding) Shall be removable.

Rationale: The DOME shielding is not intended to be an integral part of the DOME structure. Though RSS components may be connected to the DOME operating floor (e.g., seismic restraints).

[16610] RSS Assembly/Disassembly: The RSS wall closest to the DOME equipment hatch Shall be removable by remote operations.

Rationale: At a minimum, one of the shield enclosure walls needs to be moved to support reactor module installation/removal. Once the reactor module is installed, the shield enclosure will need to be reassembled.

[16606] RSS Skidding: RSS components that require the use of a skidding system for installation and removal Shall have features that support jacking of the component for installation and removal of the skidding system and associated components/equipment (e.g., turntable).

Rationale: Components that use a skidding system for installation or removal activities will need to be jacked for installation of sliding tracks, turntable, dunnage, etc. These components need to have features that allow for interface with hydraulic jacks.

[96810] RSS Overall Size: The RSS enclosure Shall fit within a space envelope of {43 ft L x 29 ft W x 23 ft H}.

Rationale: Dimensions derived from size of a high cube container (20 ft L x 8 ft W x 9.5 ft H) with 3.5 ft gap between each container surface and the shield enclosure, and a shield thickness of 7 ft (3 ft for the floor shield). An additional 2 ft were added to the length to account for the effects of shielding penetrations.

[98007] Stay Clear Space Allocation: The RSS System Shall maintain a 10 ft clearance from the DOME equipment hatch “stay clear” area.

Rationale: A laydown area is needed for equipment installation and removal of equipment from the DOME containment.

[98008] Gantry Crane Space Allocation: The RSS System Shall maintain a 4 ft clearance on each side of the shielding enclosure perpendicular to the equipment hatch.

Rationale: A 4 ft clearance is expected to be needed for installation of gantry crane tracks.

[96769] RSS Demonstrator Penetrations: RSS Shall have removable roof sections to allow demonstrators to install custom penetrations through the RSS enclosure.

Rationale: Roof sections are expected to be reconfigurable to allow for penetrations through the shield enclosure. Demonstrators are required to ensure that any demonstrator-supplied custom penetration through the RSS has sufficient shielding capability to maintain required dose rates.

[96763] Configurable Shielding: The RSS may have different configurations for shutdown and operating conditions.

Rationale: This is not a requirement, but a design consideration. Only gamma shielding is required when the reactor is shutdown. If needed, sections of shielding may be removed to facilitate reactor removal or other activities after reactor shutdown. This is unlikely to be practical as the gamma shielding is expected to be the outer layer of the shield enclosure.

1 ### A.1.2 Electrical

[89067] RSS Electrical Penetrations: The RSS Shall provide the following electrical penetrations:

{Thirty-two} 4” conduits.

Rationale: Electrical penetrations through the RSS enclosure are needed for reactor instrumentation and controls.

[111843] MCC Capacity: A Motor Controller with soft start capabilities Shall be provided to control a shielding water pump motor of up to 15 HP.

Rationale: The same pump motor capacity as used for the DOME HRS secondary pump is specified at this stage of the design. It is expected that the actual required pump motor rating will be reduced to 5 to 10 HP, once shielding water flow requirements are finalized.

[111844] Shield Water Pump Power: Power to the shielding water pump Shall be provided from N-PP-202.

Rationale: This power source was selected to ensure the shielding water pump is kept on the same power source as the rest of the DOME test bed equipment (the main MFC-767 service). While N-PP-203 is closer to the conceptual location of the shielding water pump, it is powered from the MFC-768 supply.

[111845] 120V Receptacle: A 120V GFCI receptacle, fed from N-LP-720, Shall be provided in the vicinity of the shielding water pump.

Rationale: For convenience in maintenance activities.

1 **A.1.3 Instrumentation and Controls**

[98029] RSS Leak Detection: The RSS system Shall have the capability to detect water (or other liquid) leakage inside the shielding enclosure.

Rationale: Water or other liquid is expected to be needed for cooling the shielding enclosure and shield penetrations. This requirement allows operators to identify leakage and take appropriate actions.

[111846] Water Temperature Instrumentation: Safety {class/significant} Instrumentation Shall be provided to monitor the temperature of the test bed shielding water.

Rationale: A peak shield water temperature is expected to be a TSR limit that ensures sufficient capacity to remove decay heat from reactor for the duration of the postulated coping period. This instrumentation is expected to initiate an alarm that directs operator to shutdown the reactor. An automatic reactor trip function can be implemented if needed. Safety classification of this instrument is yet to be determined, based on the hazard and accident analyses.

[111847] Water Temperature: The measured shield water temperature Shall be representative of the average shield water temperature.

Rationale: This value will be used to ensure adequate decay heat removal. Location of instrumentation needs to be selected so that temperatures being monitored are representative.

[111848] Water Temperature Range: The measurement range of the shielding water temperature instrument Shall be 40 to 212°F.

Rationale: Normal shield water temperature will be no lower than the temperature of the chilled water. If the shield water temperature reaches 212°F some shield water will start to boil, possibly releasing steam into the containment.

[112125] RSS Temperature Accuracy: All safety related RSS temperature instruments Shall have a minimum accuracy of {+/- 1°F}.

Rationale: Minimum accuracy required for proper monitoring of critical temperatures.

[111850] Large Water Leak: Safety {class/significant} instrumentation Shall be provided to detect a large shielding water leak that threatens the loss of shielding safety function.

Rationale: While the reactor is in operation the shield water is expected to perform a safety significant function to protect collocated workers from harmful dose rates. A safety significant leak detection instrumentation (e.g., water level or area dose rate) is expected to be required for shutting down the reactor upon detection of degrading shielding function. Safety classification of this instrument is yet to be determined, based on the hazard and accident analyses.

[111862] RSS Pump Discharge Pressure: Instrumentation Shall be provided to monitor the pressure on the discharge of the shielding water pump.

Rationale: Good engineering practice to protect equipment and monitor performance. This is especially beneficial due to shielding water flow potentially being controlled by a throttle valve downstream of the pump.

[111860] RSS Water pH: Instrumentation Shall be provided to monitor the pH of the shielding water.

Rationale: Use of Aluminum as a water tank material raises concerns about hydrogen formation. The probability of hydrogen formation from a reaction between water and aluminum is reduced if the pH of the water is kept between 5 and 6.

[111861] RSS Concrete Temperature: Instrumentation Shall be provided to monitor the reactor shield enclosure concrete temperature.

Rationale: Provide assurance that concrete temperature limits are not exceeded.

[111863] RSS Hx Chilled Water Temperatures: Instrumentation Shall be provided to monitor the heat exchanger chilled water supply and return temperatures.

Rationale: Heat exchanger flow rates and temperatures allow operators to monitor and control the heat removal from the shield enclosure.

[111864] RSS Hx Shield Water Temperatures: Instrumentation Shall be provided to monitor the heat exchanger shielding water supply and return temperatures.

Rationale: Heat exchanger flow rates and temperatures allow operators to monitor and control the heat removal from the shield enclosure.

[111865] RSS Hx Chilled Water Flow Rate: Instrumentation Shall be provided to monitor the flow rate of chilled water through the heat exchanger.

Rationale: Heat exchanger flow rates and temperatures allow operators to monitor and control the heat removal from the shield enclosure.

[111866] RSS Hx Shield Water Flow Rate: Instrumentation Shall be provided to monitor the flow rate of shielding water through the heat exchanger.

Rationale: Heat exchanger flow rates and temperatures allow operators to monitor and control the heat removal from the shield enclosure.

[111872] RSS Fail-Open Valves: All remotely operated valves used for heat removal from the shield enclosure Shall fail in the fully open position.

Rationale: This ensures that a loss of air, loss of power, or equipment failure does not prevent the cooling of the DOME shield enclosure.

1

A.1.4 Mechanical

[98017] RSS Mechanical Penetrations: The RSS Shall provide the following mechanical penetrations:

{One 36” x 50”} penetration

{Two 18” x 18”} penetrations

Two 4” NPS penetrations

Four 1” NPS penetrations

Rationale: Mechanical penetrations are needed for reactor demonstrator process lines, shield enclosure cooling lines (air and water), and spare penetrations for reactor vendor use.

[98010] RSS Cooling Capacity: The RSS Shall be capable of removing {100 KW} of heat from the shielding enclosure during normal operations.

Rationale: The shielding enclosure will be designed to minimize the release of activated argon (Ar-41). This limits dose rate contribution from Ar-41 and limits the dose released to the public. With minimum air release from the shielding enclosure, heat released by the reactor module will need to be removed by the shielding or a supporting heat removal system to maintain the RSS and reactor components within their specified temperature limits.

[98011] RSS Air Leakage: The RSS System Shall limit the release of air from inside the shielding enclosure to less than {100 ACFM}.

Rationale: Limiting the release of air also limits the release of activated Argon from the shielding enclosure to the DOME containment atmosphere. This limits the dose rate to personnel outside of the DOME containment and limits the dose release to the public through the DOME containment ventilation system.

[98031] RSS Decay Heat Removal: The RSS system Shall passively dissipate decay heat characterized by the following table (using a linear function between tabulated points):

Time (s)	Power (kW)
0	700
10	392.38
100	238.7
1000	141.73
3600	104.26
10000	80.55
100000	41.98
259200	30.58

Rationale: The amount of decay heat at the time of shutdown is dependent on the power levels at which the reactor operated, and the amount of time spent at those power levels. The amount of decay heat estimated for this requirement corresponds to the estimated decay heat of a reactor operating at 10 MW, with initial decay heat value of 7% of the power level that the reactor operated at prior to shutdown. Ref. ECAR-5226.

[111938] Shield Water: Demineralized water with a pH value between 5 and 6 Shall be used for the shield cooling loop.

Rationale: Use of demineralized water will minimize the activation of water, thus reducing dose rate to collocated workers.

Use of Aluminum as a water tank material raises concerns about hydrogen formation. The probability of hydrogen formation from a reaction between water and aluminum is reduced if the pH of the water is kept between 5 and 6.

[98028] RSS Drainage Path: The RSS system Shall provide a drainage path for liquids to flow from inside the shield enclosure to the operating floor of the DOME containment.

Rationale: Water or other liquid is expected to be needed for cooling the shielding enclosure and shield penetrations. This requirement ensures that postulated leaks will not result in internal flooding of the shielding enclosure. The capacity of this drainage path is expected to be based on the postulated leak rate and total liquid inventory.

[111874] RSS Chilled Water Temperature Range: The shield cooling heat exchanger Shall be rated for a chilled water temperature range of {40 to 104°F}.

Rationale: Establish criteria for equipment reliability.

[111875] Shield Water Temperature Range: The shield cooling heat exchanger Shall be rated for a shielding water temperature range of {40 to 212°F}.

Rationale: Establish criteria for equipment reliability.

[111876] RSS Chilled Water Flow Range: The shield cooling heat exchanger Shall be rated for a chilled water flow rate of at least {80 GPM}.

Rationale: Establish criteria for equipment reliability.

[111877] Shield Water Flow Range: The shield cooling heat exchanger Shall be rated for a shielding water flow rate of at least {40 GPM}.

Rationale: Establish criteria for equipment reliability.

[111878] RSS Hx Pressure Differential: When the shield water pump is running, the shield water pressure Shall be lower than the chilled water pressure at the shield cooling heat exchanger.

Rationale: This ensures potentially activated shielding water does not leak into the chilled water system.

[111931] RSS Expansion Tank: The shield water loop Shall be equipped with an expansion tank to accommodate changes in temperature without causing voids in the shield water tank or spills in the DOME containment.

Rationale: Volumetric expansion of water needs to be accommodated for the full range of expected shield water temperatures.

[111932] Decay Heat Removal Capacity: The shield water loop Shall have sufficient inventory to prevent boiling of the shield water in the event of a loss of shield water cooling.

Rationale: Postulated accident scenarios or equipment failure should not cause the shield water to boil.

[111933] Coping time: A coping time of {72 hours} Shall be used for design and analysis of required mitigating actions, if necessary, following a postulated loss of normal electrical power.

Rationale: This time interval is deemed to provide adequate margin for site maintenance and operations to take appropriate mitigating actions. Ideally, systems should be designed such that electric power is NOT required to mitigate accidents.

[111934] RSS Over-Pressure Protection: The shield water loop, including the shield water tank, Shall be equipped with over-pressure protection, or be designed to withstand all pressure transients.

Rationale: The structural integrity of the shield water components should not be challenged by over-pressurization.

1 A.2 Operational Requirements

2 A.2.1 Radiological Controls

[15155] Outdoor Radiation Limit: Shielding Shall be provided to limit the dose to a facility worker outside of DOME to less than 0.05 mrem/hr 50 feet from the exterior wall of the dome and ALARA.

Rationale: Ensures areas outside the DOME are maintained ALARA per 10 CFR 835, Subpart K.

[16604] Operating Dose Rate: The dose rate during reactor operation Shall be less than 5 mrem/hr at the exterior wall of DOME containment.

Rationale: Ensures areas outside the DOME are maintained ALARA per 10 CFR 835, Subpart K.

[96768] Shielding Shutdown Dose Rate: Selection of RSS shielding materials Shall be made with ALARA considerations, where dose rates 30 cm from RSS components and 90 days post shutdown do not exceed 0.5 mrem/hr outside the shielding enclosure and 5 mrem/hr inside the shielding enclosure.

Rationale: This is a performance-based requirement where the shielding design should be optimized to the greatest practical extent to ensure radiation fields generated by residual activation of the shield materials do not exceed ALARA Review Trigger Levels (LWP-15021, "ALARA Program and Implementation") at 90 days post shutdown.

Dose rates identified are after removal of reactor module from the shielding enclosure. Shielding activation can challenge the ability of operators to perform maintenance and shielding removal activities following a reactor experiment.

[96772] RSS Penetration Impact: Penetrations through the RSS Shall use labyrinth design.

Rationale: The use of labyrinth design ensures dose rate requirements can be met while minimizing the amount of additional shielding material needed.

[16608] Equipment Dose: The RSS Shall provide shielding that limits dose to facility equipment to less than or equal to 1E5 Rad over a period of 20 years.

Rationale: Specific equipment within DOME facility may have lifetime requirements.

[16615] Experiment Operational Neutron Flux: The RSS Shall provide protection from the following neutron flux limits (averaged over a 1 square meter area) at the boundaries of the experiment during operation:

Neutron	
Energy Bin (MeV)	Flux (n/cm2-s)
1.00E-08	0.00E+00
3.00E-08	0.00E+00
5.00E-08	0.00E+00
1.00E-07	0.00E+00
2.25E-07	0.00E+00
3.25E-07	0.00E+00
4.14E-07	0.00E+00
8.00E-07	0.00E+00
1.00E-06	0.00E+00
1.13E-06	0.00E+00
1.30E-06	0.00E+00
1.86E-06	0.00E+00
3.06E-06	0.00E+00
1.07E-05	0.00E+00
2.90E-05	1.48E+03
1.01E-04	5.84E+04
5.83E-04	1.49E+06
3.04E-03	1.89E+07
1.50E-02	7.34E+07
1.11E-01	1.13E+08
4.08E-01	3.28E+08
9.07E-01	3.13E+08
1.42E+00	2.24E+08
1.83E+00	9.94E+07
3.01E+00	3.58E+07
6.38E+00	4.02E+07
2.00E+01	2.69E+07
TOTAL	1.28E+09

Rationale: Limit experiment flux so that RSS will meet its dose requirements, for a reactor module size that is bounded by the outside dimensions of a 20 ft. high Conex box.

[89066] Experiment Operational Photon Flux: The RSS Shall provide protection from the following photon flux limits (averaged over a 1 square meter area) at the boundaries of the experiment during operation:

Photon	
Energy Bin (MeV)	Flux (p/cm2-s)
1.00E-02	1.33E+06
4.50E-02	4.99E+07
1.00E-01	5.19E+08
2.00E-01	1.75E+09
3.00E-01	1.35E+09
4.00E-01	1.05E+09
6.00E-01	2.96E+09
8.00E-01	4.70E+08
1.00E+00	3.74E+08
1.33E+00	4.01E+08
1.66E+00	3.18E+08
2.00E+00	2.70E+08
2.50E+00	3.01E+08
3.00E+00	2.40E+08
4.00E+00	3.73E+08
5.00E+00	2.97E+08
6.50E+00	4.03E+08
8.00E+00	6.11E+08
1.00E+01	2.49E+08
2.00E+01	4.89E+05
TOTAL	1.20E+10

Rationale: Limit experiment flux so that RSS will meet its dose requirements, for a reactor module size that is bounded by the outside dimensions of a 20 ft. high Conex box.

1 A.2.2 Operating Environment

[16120] Indoor Temperature Rating: Equipment located inside the dome Shall be able to function with ambient temperatures between 35-105°F.

Rationale: Equipment should still be operable if the air conditioning systems are temporarily unavailable. The high temperature is the maximum temperature allowed inside of containment during operation. The low end is the minimum expected temperature for an indoor environment protected against freezing.

[111014] Gas Flow Calculations: When it is conservative to do so, gas flow calculations Shall use a site altitude of 5200 ft and the normal operation range for DOME containment negative pressure (-0.1 to -0.3 in. w.g.).

Rationale: This ensures the calculations are conservative and representative of site and operating conditions.

1 A.3 Reliability Requirements

[15168] Continuous Operation: Systems supporting reactor operation Shall be designed to operate continuously for 8,000 hours per year.

Rationale: 8000 hours is considered continuous operation in a year. This will prevent equipment failures from resulting in shut down of the demonstration reactor.

[16596] RSS Fluence: The shielding Shall withstand a lifetime neutron fluence of {1E20} neutrons/cm2 while maintaining the RSS structural integrity and shielding effectiveness.

Rationale: Material properties degrade by neutron radiation. All neutron energy levels are to be included in the lifetime neutron fluence calculation.

2 A.4 DOME Facility Requirements

3 A.4.1 Structural

[16595] Floor Load: The RSS Shall not exceed a distributed floor loading of 3750 psf.

Rationale: The allowable loading limit of the concrete floor is provided in TEV-3481.

[96770] Floor Point Load 1 sq. ft.: The RSS Shall not exceed a point load of 20,000 lbs on a 1 sq. ft. area.

Rationale: The allowable loading limit of the concrete floor is provided in TEV-3481.

[96771] Floor Point Load 5 sq. ft.: The RSS Shall not exceed a point load of 100,000 lbs on a 5 sq. ft. area.

Rationale: The allowable loading limit of the concrete floor is provided in TEV-3481.

[15189] Seismic Design Category: SC SSCs Shall be designed to SDC-3 Limit State C for the structure and Limit State D for containment as defined by DOE STD-1020 and ASCE 43.

Rationale: Based on the bounding dose consequence calculations performed in ECAR-5065, "Evaluation of Microreactor Inhalation Dose Consequences," the facility and the individual reactors to be utilized are categorized as NPH design category (NDC)-3 per the criteria in DOE-STD-1020. Limit states are defined in SDS-428.

[89069] RSS Temperature Limit: The RSS Shall withstand a peak temperature of {212°F} on the inside surface of the shield enclosure.

Rationale: Based on the materials selected for the RSS, the surface temperature and peak heat flux at the inner surface of the shield enclosure will need to be controlled to maintain shield integrity and effectiveness. Shielding materials should not melt or experience excessive reduction in material strength that will prevent it from performing its safety functions (e.g., withstand SDC-3 earthquake). Moreover, the shielding effectiveness of some materials is reduced at higher temperatures (e.g., concrete – due to a reduction in the water content at temperatures greater than 212°F). Exposure to these anticipated temperature and heat flux limits cannot reduce the shielding design capability of the RSS for future demonstrators.

[89068] RSS Seismic Capability: The RSS Shall be designed to withstand SDC-3 earthquakes through the full range of anticipated temperatures (normal and accident conditions).

Rationale: Structural integrity can be degraded by elevated temperatures. The anticipated temperature ranges are expected to be different for each reactor design. As such, each demonstrator will need to calculate anticipated temperature range to demonstrate that calculated range is bounded by RSS design temperature range.

[16598] RSS Natural Hazard: The RSS Shall maintain its function and not damage adjacent SC SSCs during a design basis natural hazards event (earthquake, flood, etc.).

Rationale: Ensures safety throughout the life of the RSS and protects adjacent SC SSCs.

[15192] Flooding Design Category: SC SSCs Shall be designed to FDC-3 as defined by DOE STD-1020.

Rationale: Based on the bounding dose consequence calculations performed in ECAR-5065, "Evaluation of Microreactor Inhalation Dose Consequences," the facility and the individual reactors to be utilized are categorized as NPH design category (NDC)-3 per the criteria in DOE-STD-1020.

1 A.4.2 Environmental

[15181] Waste Production Minimization: Facility process systems Shall be designed to minimize waste production and mixing of radioactive and non-radioactive wastes.

Rationale: DOE O 420.1C Chg 3, Attachment 2, Chapter I, Section 3.b.(5).

[16603] RSS Hazardous Waste: All RSS materials Shall have an approved disposal path and minimize the generation of hazardous and mixed hazardous waste.

Rationale: Decommissioning should not be too challenging or expensive. Plans for D&D of hazardous and radioactive waste need to be approved prior to testing.

2 A.4.3 Life Safety

[15185] Standard for Fire Protection: DOE-STD-1066 Shall be followed for DOME and associated systems.

Rationale: DOE O 420.1C Chg 3, Attachment 2, Chapter II, Section 3.b.(2). INL will complete a preliminary fire hazard analysis which will define the types of fire protection systems that must be installed in the DOME facility. Moreover, each demonstrator will also complete a preliminary fire hazard analysis addressing any hazards introduce by their reactor or support systems.

[96812] RSS Facility Hazard: Exposure of RSS to high operating temperatures (normal and accident conditions) Shall not induce a facility hazard.

Rationale: Facility hazards can change as materials are exposed to high temperatures (e.g., melted polyethylene may be a flammable material). Expected shielding temperatures are dependent on materials selected as well as shielding enclosure cooling configuration (forced cooling, openings for natural convection, etc.). As shielding design develops, more specific temperature requirements can be specified for each RSS material, such as "Polyethylene in the RSS Shall not exceed [TBD] degrees F".

[16605] Fire Protection: All exposed combustible material surfaces Shall be protected by a non-combustible material.

Rationale: Design basis accident consideration.

[16599] RSS Chemical Compatibility: Materials in the RSS Shall be either compatible with materials in the experiment or have mitigating strategies for minimizing risk of adverse material interactions.

Rationale: In this requirement, compatible materials means no chemical reactions with potential to compromise the shielding or structural integrity of SSCs.

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