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TFR-2576 MARVEL Reactor Structure (MRS)

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Changing the World's Energy Future

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Idaho National Laboratory

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Technical and Functional Requirements

MARVEL Reactor Structure (MRS)

Idaho National Laboratory

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CONTENTS

1. INTRODUCTION

1.1 System Identification

This document contains the Level 3 requirements associated with the subsystems of the MARVEL Reactor Structure (MRS) in the Microreactor Applications Research Validation and Evaluation (MARVEL) project:

- Primary Coolant Subsystem (PCS)
- Secondary Coolant Subsystem (SCS)
- Primary Coolant Management Subsystem (PCMS)
- Secondary Coolant Management Subsystem (SCMS)
- Inert Gas Subsystem (IGS)
- Secondary Cover Gas Subsystem (SCGS)
- Guard Vessel Subsystem (GVS)
- Reactor Support Frame (RSF)
- Reactor Shielding Subsystem (SHLD)
- Reflector Support Subsystem (RSS)
- Secondary Support Structure (SSS)
- Secondary Output Structure (SOS)
- Upper Confinement Subsystem (UCS)
- Upper Shielding Subsystem (USS)

The MRS subsystems are responsible for transferring thermal energy from the core to the power generation equipment while simultaneously supplying supporting coolants and gases and providing structural support for various equipment. A diagram of how these subsystems interface and support one another is provided in Section 2.3.

1.2 Limitations of the T&FR

Safety classifications are pending the issuance of the MARVEL Preliminary Documented Safety Analysis (PDSA).

Design of the PCMS subsystem to fulfill the NaK drain, shielding, and disposal functions is considered part of decommissioning and disposal (D&D), and will be completed prior to termination of operations.

1.3 Ownership of the T&FR

The TREAT Engineering Manager is the owner of this T&FR. The current Cognizant System Engineer for the MARVEL Reactor Structure is responsible for the overall development and maintenance of the T&FR.

1.4 Definitions/Glossary

None at the time of this revision.

1.5 Acronyms

ALARA	As Low As Reasonably Achievable
ASME	American Society of Mechanical Engineers
BPVC	Boiler and Pressure Vessel Code
COR	Code of Record
ECAR	Engineering, Calculation, and Analysis Report
FS	Fuel Subsystem
GV	Guard Vessel
GVS	Guard Vessel Subsystem
ICS	Instrumentation and Control System
IGS	Inert Gas Subsystem
I&C	Instrumentation and Control
IHX	Intermediate Heat Exchanger
IRF	Inherent Reactivity Feedback
LOCA	Loss of Coolant Accident
MARVEL	Microreactor Applications Research Validation and Evaluation
MBSE	Model-Based Systems Engineering
MRS	MARVEL Reactor Structure
NaK	Sodium-Potassium Eutectic Allow
NSR	Non-Safety Related
NSR-AR	Non-Safety Related with Augmented Requirements
PCB	Primary Coolant Boundary
PCMS	Primary Coolant Management Subsystem

PCS	Primary Coolant System
PDSA	Preliminary Documented Safety Analysis
RSF	Reactor Support Frame
RSS	Reflector Support Subsystem
SCGS	Secondary Cover Gas Subsystem
SCMS	Secondary Coolant Management Subsystem
SCR	Stationary Core Reflector Subsystem
SCS	Secondary Coolant Subsystem
SDD	System Design Description
SHLD	Reactor Shielding Subsystem
SOS	Secondary Output Structure
SR	Safety Related
SSCs	Structures, Systems, and Components
SSS	Secondary Support Structure
TREAT	Transient Reactor Test Facility
T-REXC	TREAT Facility Micro-Reactor Experiment Cell
UCS	Upper Confinement Subsystem
UHP	Ultra-High Purity
USS	Upper Shielding Subsystem

2. GENERAL OVERVIEW

2.1 System Functions

2.1.1 PCS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

PCS.1: Remove Heat from Core Region

PCS.2: Transfer Heat to IHX

PCS.3: Transfer Heat & Decay Heat to Guard Vessel

PCS.4: Return Primary Coolant to Core Region

PCS.5: Prevent Primary Coolant and Cover Gas Leaks

PCS.6: Provide Structural Support of SSCs Connected to Primary Coolant Boundary

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

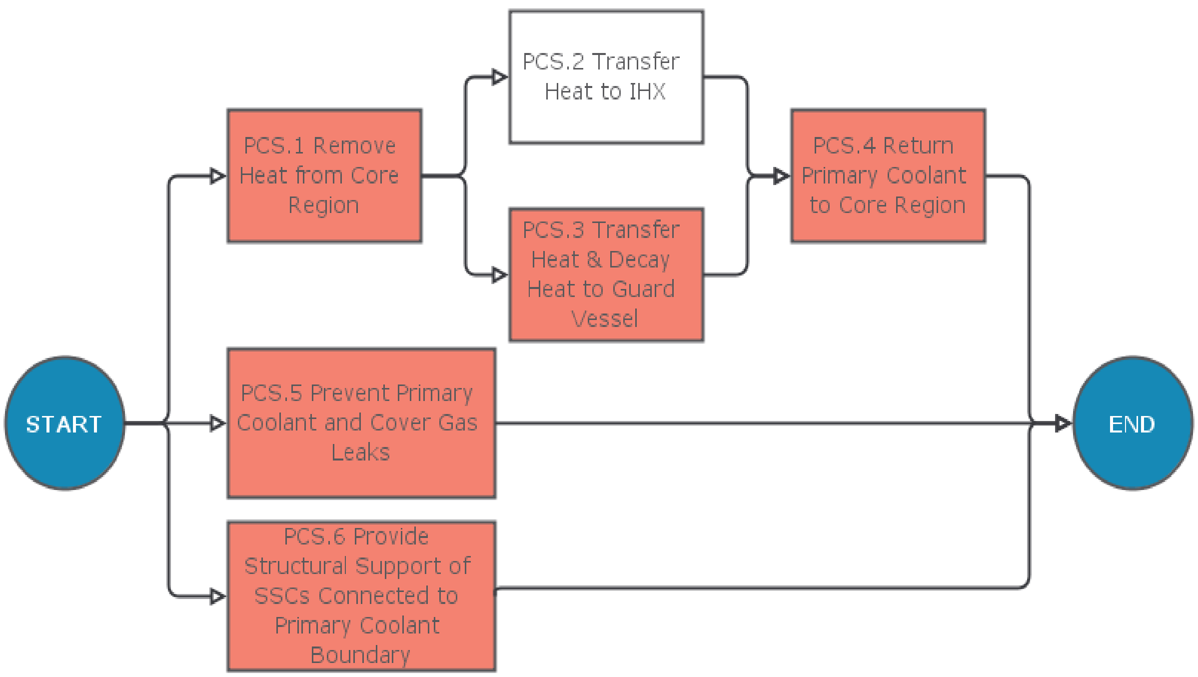

Figure 1. Primary Coolant Subsystem Functional Diagram.

2.1.2 SCS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SCS.1: Extract Heat from Primary Coolant

SCS.2: Circulate Heat to Stirling Engines

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

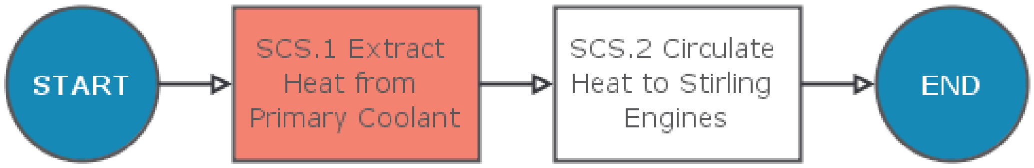

Figure 2. Secondary Coolant Subsystem Functional Diagram.

2.1.3 PCMS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

PCMS.1: Store NaK

PCMS.2: Transfer NaK to Reactor

PCMS.3: Measure Amount of NaK Delivered to Reactor

PCMS.4: Drain NaK from Reactor

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

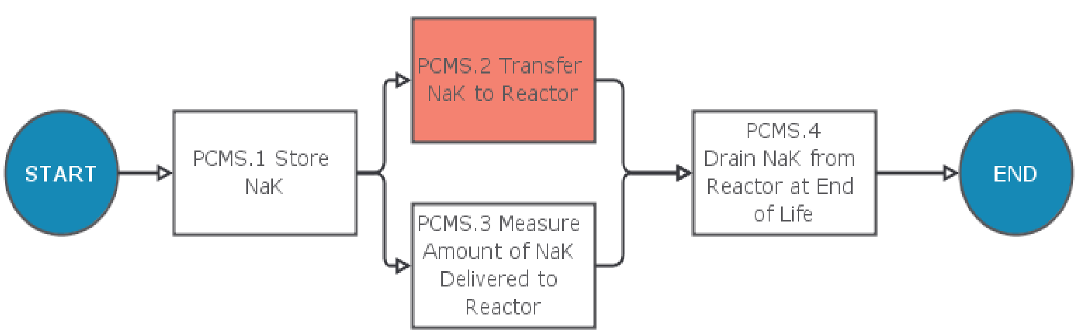

Figure 3. Primary Coolant Management System Functional Diagram.

2.1.4 SCMS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SCMS.1: Store GaInSn

SCMS.2: Transfer GaInSn to SCS

SCMS.3: Measure Amount of GaInSn Delivered to SCS

SCMS.4: Drain GaInSn from Reactor

SCMS.5: Facilitate GaInSn Disposal

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

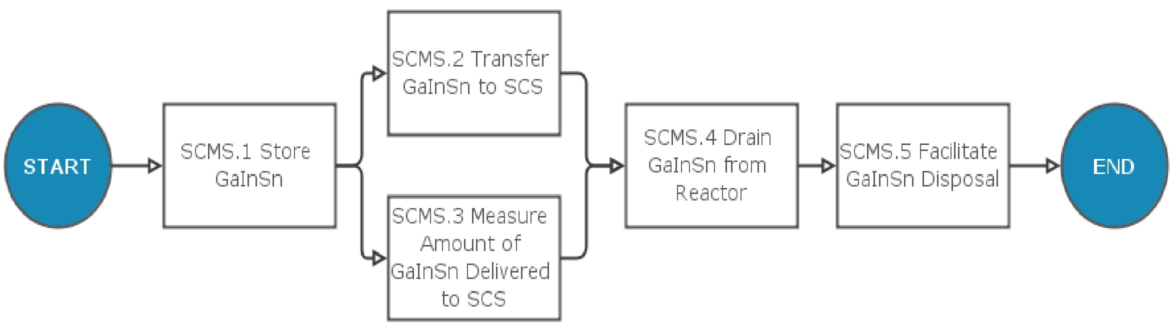

Figure 4. Secondary Coolant Management System Functional Diagram.

2.1.5 IGS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

IGS.1: Store Argon Gas

IGS.2: Dry Argon Gas

IGS.3: Transfer Argon Gas to Primary Coolant Boundary

IGS.4: Transfer Argon Gas to Guard Vessel

IGS.5: Transfer Argon Gas to CIA Rod Sheath

IGS.6: Provide Capability to Sample Cover Gas

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

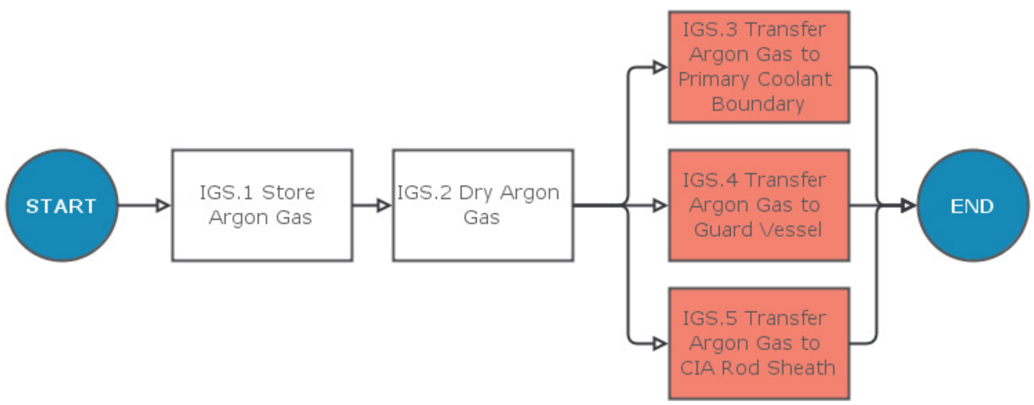

Figure 5. Inert Gas System Functional Diagram.

2.1.6 SCGS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SCGS.1: Store Helium Gas

SCGS.2: Transfer Helium Gas to IHX Headspaces

SCGS.3: Remove Potentially Contaminated Cover Gas from IHXs

SCGS.4: Provide Ability to Sample Potentially Contaminated Cover Gas

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

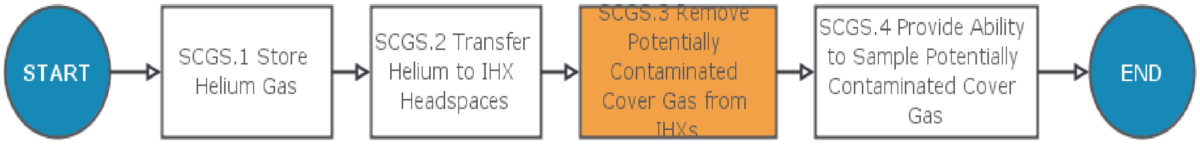

Figure 6. Secondary Cover Gas System Functional Diagram.

2.1.7 GVS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

GVS.1: Remove Heat from Primary Coolant Boundary and Surrounding Components

GVS.2: Transfer Heat to T-REXC

GVS.3: Collect NaK Leaks at Low Point

GVS.4: Prevent Cover Gas Leaks from Guard Vessel

GVS.5: Provide Structural Support of SSCs Connected to Guard Vessel

The following diagram clarifies the functions performed by the subsystem in sequential fashion. Functions highlighted in red are those that are Safety-Related (SR) per the MARVEL safety basis. Functions highlighted in orange are those that are Non-Safety-Related with Augmented Requirements (NSR-AR). Other Non-Safety Related (NSR) functions are not colored. The classification of these functions is derived from ECAR-6440.

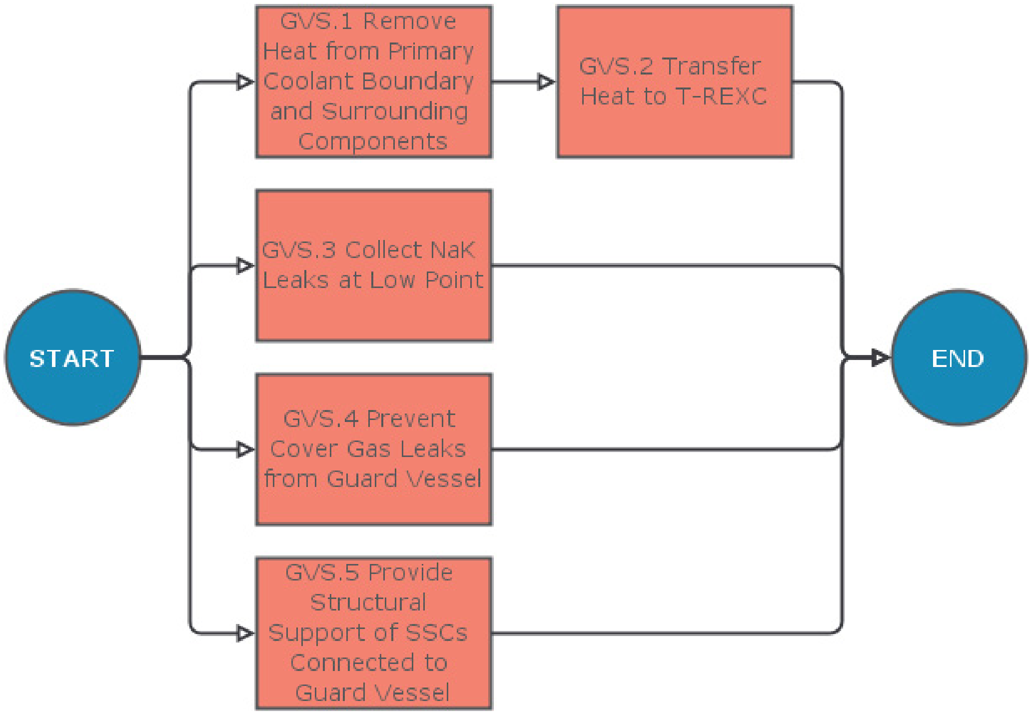

Figure 7. Guard Vessel Subsystem Functional Diagram.

2.1.8 RSF Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

RSF.1: Support the reactor within the TREAT pit

2.1.9 SHLD Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SHLD.1: Support Protection of T-REXC Pit from Activation

SHLD.2: Support Protection of Electronics from Radiation Damage

SHLD.3: Support the Protection of Operators in TREAT from Radiation Exposure

2.1.10 RSS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

RSS.1: Support the Stationary Core Reflectors

RSS.2: Maintain Alignment and Free Rotation of the Control Drums

2.1.11 SSS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SSS.1: Support the Stirling Engines

2.1.12 SOS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

SOS.1: Support the Stirling Engines

SOS.2: Isolate Stirling Engine Vibration

2.1.13 UCS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

UCS.1: Provide Controlled Pathway for Air Supply and Exhaust from T-REXC

UCS.2: Confine Leaked Liquids

UCS.3: Minimize Ingress or Egress of Gases, Fumes, Smoke, or Vapor Through Uncontrolled Pathways to T-REXC

2.1.14 USS Functions

The subsystem performs the following functions. Each function is traceable to the functional requirements in Section 3.

USS.1: Support the Protection of Operators and Equipment in TREAT from Radiation Exposure

USS.2: Facilitate Access to the Upper Confinement Space

USS.3: Provide Structural Support for Mounted Equipment

2.2 System Classification

The table below provides the classifications for the subsystems of the MRS based on the highest ranking (most important) requirements identified for the subsystems. Note that this classification is pending issuance of the project Preliminary Documented Safety Analysis (PDSA).

Table 1. MRS Subsystem Classifications.

Acronym	Subsystem	Classification
PCS	Primary Coolant Subsystem	Safety Related (SR)
SCS	Secondary Coolant Subsystem	SR
PCMS	Primary Coolant Management Subsystem	SR
SCMS	Secondary Coolant Management Subsystem	Not Safety Related (NSR)
IGS	Inert Gas Subsystem	SR
SCGS	Secondary Cover Gas Subsystem	Non-Safety Related with Augmented Requirements (NSR-AR)
GVS	Guard Vessel Subsystem	SR
RSF	Reactor Support Frame	SR
SHLD	Reactor Shielding Subsystem	SR
RSS	Reflector Support Subsystem	SR
SSS	Secondary Support Structure	SR
SOS	Secondary Output Structure	SR
UCS	Upper Confinement Subsystem	NSR-AR
USS	Upper Shielding Subsystem	SR

2.3 Basic Operational Overview

The following diagram shows the overall system architecture of the MRS and how each of the subsystems (in blue) interface. Grey boxes surrounding the system boundary represent interfacing systems not within the scope of the MRS. Red lines represent thermal interfaces, blue lines represent fluid interfaces, green lines represent gas interfaces, teal lines represent instrumentation and control (I&C) interfaces, purple lines represent nuclear interfaces, and black lines represent important mechanical or structural interfaces. The MRS subsystems are described in more detail in the following subsections.

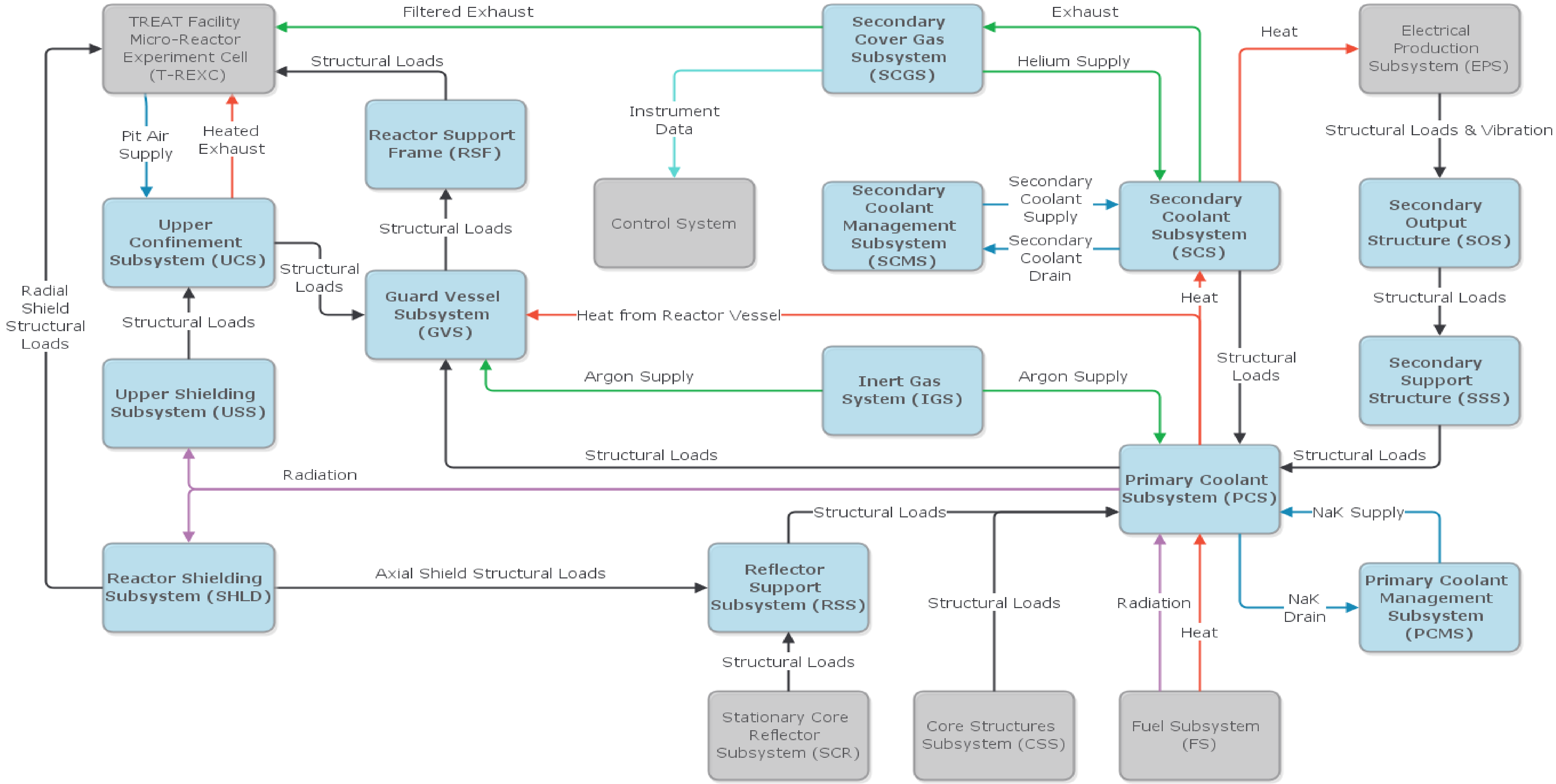

Figure 8. MARVEL Reactor Structure Architecture and Interfaces.

2.3.1 PCS Basic Operational Overview

The PCS is a high temperature, low pressure boundary that leverages eutectic sodium-potassium (NaK) alloy as a coolant to remove heat from the Fuel Subsystem (FS) using natural convection. During normal operation the hot coolant rises out of the core into the distribution plenum. The SCS in the distribution plenum removes heat from the primary coolant, and buoyancy forces drive the cooled NaK downward into one of the four insulated PCS downcomer pipes. The piping returns the coolant to the lower plenum where it will be again pulled into the core, completing the loop. During postulated accident events the PCS conducts decay heat to the guard vessel for convection to the TREAT Facility Micro-Reactor Experiment Cell (T-REXC). This path of heat exchange also occurs during normal operation.

Structurally, the PCS is seated on the stand at the distribution plenum and supports the weight of most MRS subsystems except the guard vessel. The hanging arrangement sets the neutral plane of thermal expansion to accommodate unrestrained expansion at temperature. The PCS includes an argon gas headspace above the primary coolant level supplied by the IGS. Coolant makeup and draining functions are provided by the PCMS.

2.3.2 SCS Basic Operational Overview

The SCS removes fission heat from the PCS, transferring the heat through an Intermediate Heat Exchanger (IHX) to the engines through a natural convection loop for power generation. The secondary coolant fills the IHX to an opening at the top where the engine is suspended partially in the coolant. The design follows a pipe-in-pipe arrangement, where the fluid in the outer annulus pulls heat from the primary coolant, is driven up by buoyancy forces to the engine, and sinks through the center downcomer pipe once the heat is removed by the engine. Coolant filling and draining is provided by the interfacing SCMS. The SCS is filled with an inert helium gas blanket as well to prevent reaction of any NaK which might leak across the IHX boundary from the PCS. To mitigate the potential for corrosion of the PCS-to-IHX interface by the secondary coolant, a sacrificial metal liner is inserted on the secondary side of the IHX. This liner can be inspected and replaced during Stirling engine replacement operations. A loose running fit is used in combination with a boron nitride thermal paste and lifting features to ensure removability for maintenance, and a gasketed, bolted connection ensures it will remain fixed and can contain potential primary coolant leaks through the IHX. The thermal paste also aids heat transfer across the liner to the secondary coolant.

2.3.3 PCMS Basic Operational Overview

The PCMS provides the equipment necessary to purify and fill the primary coolant.

2.3.4 SCMS Basic Operational Overview

The SCMS provides the equipment necessary to purify, fill, and drain the secondary coolant.

2.3.5 IGS Basic Operational Overview

The IGS supplies ultra-high purity (UHP) argon to the primary coolant boundary, guard vessel, the CIA rod housing and the upper confinement space to prevent NaK reactions with air.

2.3.6 SCGS Basic Operational Overview

The SCGS provides a helium cover gas to the IHX for chemistry control of the secondary coolant, vents the helium cover gas from the IHX headspace, and filters the exhaust stream to contain the evolved radionuclides. This offgas is transferred to the T-REXC ventilation system for downstream processing.

2.3.7 GVS Basic Operational Overview

The GVS serves as the secondary confinement boundary for the primary coolant, enveloping the bottom and sides of the PCS. During normal operations, anticipated events, and postulated accident scenarios heat is conducted and convected from the PCS into the inert atmosphere of the guard vessel (GV) which then passively transfers it to the T-REXC. The GV supports the reactor by transferring the weight of the MRS subsystems to the RSF. It also contains features that allows for instrument cables and wiring to be passed through the pressurized inert gas boundary.

In the event of a loss of coolant accident (LOCA), the guard vessel prevents the core from being uncovered by providing a controlled, inert environment for the coolant to flow into. If primary coolant leaks into the guard vessel, the fluid level in the guard vessel will rise as liquid level in the primary subsystem falls, until both subsystems equilibrate. The vessel has a sloped, dished bottom head to ensure any NaK leaked drains down into the sump at the bottom of the vessel, facilitating leak detection by the reactor instrumentation subsystem (RIS).

2.3.8 RSF Basic Operational Overview

The RSF transfers the load from the GVS (and therefore all the MRS subsystems beside the lower radial shield) to the T-REXC structure.

2.3.9 SHLD Basic Operational Overview

The SHLD subsystem consists of both axial and radial shielding components. Axial shields are located on top of the upper RSS plate to reduce gamma and neutron radiation from the core into the upper confinement space. Radial shields surround the lower portion of the GVS to reduce gamma and neutron activation of the T-REXC structures.

2.3.10 RSS Basic Operational Overview

The RSS supports and locates the Stationary Core Reflector Subsystem (SCR) and provide vertical support for the control drums. The RSS is suspended from the PCS distribution block by bolted structural straps which utilize a turnbuckle to allow for adjustment and leveling of the support plates. The stainless-steel support plates are each formed from four quarter circle segments which are bolted together around the lower core barrel.

2.3.11 SSS and SOS Basic Operational Overview

Four SSS assemblies are connected to the top the PCS distribution block, each supporting a SOS structure. The SOS suspends the stirling engines in the pool of secondary coolant. The SOS is also responsible for isolating the vibration caused by the operating engines to minimize impacts on the rest of the MRS. Each SOS assembly is designed to be assembled outside the pit and then lowered via lifting eye onto the SSS.

2.3.12 UCS Basic Operational Overview

The UCS is located above the primary coolant distribution block and encloses the upper confinement space housing the Stirling engines. The structure provides secondary confinement in the event of fission product release from the primary coolant boundary. The UCS interfaces with the T-REXC HVAC system for fresh air supply and suspect exhaust. The subsystem also includes the patch panel which provides mechanical and electrical system feedthroughs into the reactor headspace. Additionally, access is provided through the upper lid for control drum shafts to penetrate through the PCS distribution block and for control drum locking tools. The structure is removable such that the space can be accessed by overhead handling equipment for maintenance events and Stirling engine removal and replacement.

2.3.13 USS Basic Operational Overview

The USS sits atop the UCS and provides shielding for reactivity control electronics installed above it. The USS is removeable such that the upper confinement space can be accessed by overhead handling equipment for maintenance events and Stirling engine removal and replacement.

3. REQUIREMENTS AND BASES

3.1 Requirements

This section provides the requirements that must be met in the system design and will require design verification. The MARVEL project requirements are stored in the IBM DOORS Next software tool. This software was used to generate this document. Therefore, each requirement has a unique number in brackets [ ] to the left of the requirement used to identify the requirement in the database and to provide a hyperlink back to the software. Each requirement also includes a bolded title summarizing the concept and a rationale statement in italics explaining where the requirement comes from or why it provides value. Finally, the links within the requirements database showing how requirements relate to one another are displayed beneath the rationale. The Level 3 requirements in this document are derived from the Level 2 requirements contained in FOR-868, "Microreactor Applications Research Validation and Evaluation (MARVEL) Project," and FOR-684, "Transient Reactor Test (TREAT) Facility Micro-Reactor Experiment Cell (T-REXC)" The calculational and design documents that verify that these requirements have been met by the design are listed in VM-118, "MARVEL Design Verification Matrix."

3.2 Bases

Each requirement in this document is followed by a "rationale" statement which explains why the requirement exists, why it is specified in a particular manner, and why it has particular value.

3.3 References

See Appendix A for a complete list of references and source documents.

3.4 General Requirements

3.4.1 System Functional Requirements

3.4.1.1 PCS Functional Requirements

[109371] Core Region Heat Removal: The PCS shall be capable of removing at least 97.75 kWth of heat from the core region during normal operations, anticipated events, and postulated accidents.

Rationale: Removing heat (including decay heat) from the core is a fundamental safety function of the reactor. The total heat removal rating includes a 15% safety margin above the nominal 85 kW rating of the reactor.

Derived By: [105317] Decay Heat to Ultimate Heat Sink, [105315] Core Heat Removal

Linked From: PCS.1, PCS.2, PCS.3, PCS.4

[109372] Normal Maximum Cladding Temperature: The PCS shall remove heat from the core region such that the fuel cladding temperature remains beneath 764°C during normal operation and anticipated events.

Rationale: The PCS must protect the specified allowable fuel design limits during normal operation. Expected operational temperatures are well below this limit, but 650 C should conservatively protect the fuel cladding fission product containment function.

The maximum permitted cladding temperature is further limited to 767.6 °C, the NaK saturation temperature at 84.2 kPa which is the atmospheric pressure at 1560 m or 5122 feet of elevation above the sea level at TREAT [see TREAT addendum SAR-420-ADD-1]) in order to prevent localized boiling, which could result in clad burnout and loss of coolable geometry.

This clad limit is further restricted to 763 °C in order to include ±4.0 °C thermocouple instrumentation uncertainties (see section 3.3 of ECAR-6332). This hot spot clad limit is then excluding any possibility of localized film boiling which could compromise the clad integrity.

Derived By: [105315] Core Heat Removal, [105317] Decay Heat to Ultimate Heat Sink

Linked From: PCS.1

[109373] Postulated Accident Cladding Temperature: The PCS shall remove heat from the core region such that the fuel cladding temperature remains beneath 764°C throughout the duration of postulated accidents.

Rationale: The PCS must protect the specified allowable fuel design limits during postulated accidents. ASME BPVC Section III Div 5 has qualified data on the behavior of the selected cladding material through 815 deg C. Properties are expected to be stable until 950 deg C, but data is not similarly qualified. The likely fuel failure mode is due to over-pressurization due to hydrogen dissociation at high temperatures. The maximum clad temperature is further limited to be less than 767.6 °C, the NaK saturation temperature at 84.2 kPa which is the atmospheric pressure at 1560 m or 5122 feet of elevation above the sea level at TREAT [see TREAT addendum SAR-420-ADD-1]) in order to prevent localized boiling, which could result in clad burnout and loss of coolable geometry. This clad limit is further restricted to 763 °C in order to include ±4.0 °C thermocouple instrumentation uncertainties (see section 3.3 of ECAR-6332). This hot spot clad limit is then excluding any possibility of localized film boiling which could compromise the clad integrity.

Derived By: [105315] Core Heat Removal, [105317] Decay Heat to Ultimate Heat Sink

Linked From: PCS.1

[116365] Maximum Core Outlet Temperature: The maximum core outlet coolant temperature shall remain below 539ºC.

Rationale: This helps ensure peak cladding temperatures remain below their maximum limits.

Derived By: [105315] Core Heat Removal

[109986] External Neutron Source Support: The PCS shall provide a means to securely house a startup neutron source near the reactor core.

Rationale: A startup neutron source will be needed to achieve initial criticality and to keep startup instrumentation within range.

Derived By: [105344] Neutron Source Accommodation

[115003] Maximum Reactor Heat-up Rate: The maximum heat-up rate for the primary coolant shall be limited to 150ºC/hr unless and until new limits are determined via structural mechanical analysis.

Rationale: Rapid temperature changes in the primary coolant can induce stresses in the primary coolant vessel which can shorten its useful life. Limiting the rate of change to this level ensures the vessel can conservatively exceed the design life of the MARVEL project.

Derived By: [105326] Reactor Structure Design for Operating Environment

Linked From: PCS.1

3.4.1.2 SCS Functional Requirements

[109374] Heat Transfer to Secondary Coolant: The SCS shall be capable of transferring power to the Stirling engines under hot full power conditions.

Rationale: Transferring power from the primary coolant to the end user is the fundamental function of the secondary coolant system. Heat transfer is not credited for safety.

Derived By: [105316] Heat Transfer to End Users

Linked From: SCS.1, SCS.2

3.4.1.3 PCMS Functional Requirements

[109387] Primary Coolant Storage Prior to Filling: The PCMS shall be designed to store at least 180 kg of NaK prior to initial filling.

Rationale: The PCMS should have at least the amount of primary coolant needed to fill the primary coolant boundary up to the designed liquid level calculated in ECAR-6586.

Derived By: [105322] Primary Coolant Supply

Linked From: PCMS.1

[115366] PCS Fill: The PCMS shall provide NaK to the PCS according to the specified interface.

Rationale: The PCMS is responsible for the initial fill of the PCS.

Derived By: [105322] Primary Coolant Supply

Linked From: PCMS.2

[115119] Primary Coolant Transfer Measurement: The PCMS shall provide the ability to measure the amount of NaK delivered to the reactor.

Rationale: Since there is no way to measure the level of the primary coolant once inside the reactor vessel, the amount of NaK transferred into the system will be used to verify that the correct initial primary coolant level is achieved.

Derived By: [105322] Primary Coolant Supply

Linked From: PCMS.3

[109389] Primary Coolant Draining/Removal: The PCMS shall provide a means to drain or remove the primary coolant from the reactor vessel at the end of life.

Rationale: The primary coolant will need to be drained from the reactor vessel during final decommissioning of the reactor.

Derived By: [105324] Liquid Waste Management, [105330] Reactor Structure Decommissioning

Linked From: PCMS.4

3.4.1.4 SCMS Functional Requirements

[115364] Secondary Coolant Transfer Capability: The SCMS shall be capable of transferring the secondary coolant into the IHX volumes.

Rationale: The SCMS is responsible for the initial fill of the SCS.

Derived By: [105332] Reactor Structure Maintenance and Replacement, [105325] Secondary Coolant Supply

Linked From: SCMS.2

[109384] Secondary Coolant Transfer Measurement: The SCMS shall include a method of determining the amount of secondary coolant delivered to the IHXs.

Rationale: The level of secondary coolant in the IHX should be measured and reported to the operator to prevent overfilling.

Derived By: [105325] Secondary Coolant Supply

Linked From: SCMS.3

[115365] Maintain Secondary Coolant Purity: The SCMS shall maintain the purity of the secondary coolant during all transfer and storage operations.

Rationale: Materials and operations must be chemically compatible

Derived By: [105325] Secondary Coolant Supply

Linked From: SCMS.1

[115363] Secondary Coolant Removal: The SCMS shall be capable of removing sufficient secondary coolant from IHX liner to permit changing of IHX liner within ALARA principles.

Rationale: Permit maintenance on Stirling engine without spilling of secondary coolant.

Derived By: [105332] Reactor Structure Maintenance and Replacement, [105331] Reactor Structure Inspection and Testing

Linked From: SCMS.4, SCMS.5

3.4.1.5 IGS Functional Requirements

[109386] Cover Gas Storage Capacity: The IGS shall be capable of storing 900 SCF (Three standard 300 SCF bottles) of argon gas outside of the reactor.

Rationale: Argon storage is required for initial filling and should there be cover gas loss during the lifespan of the MARVEL reactor. At least three times the volume of space supplied by the subsystem should be provided.

Derived By: [105320] Cover Gas Supply

Linked From: IGS.1

[109377] Cover Gas Filling: The IGS shall be capable of connecting to and transferring argon gas to the primary coolant pressure boundary, guard vessel pressure boundary, and the CIA rod sheath.

Rationale: An inert blanket should be maintained in the primary coolant boundary, the upper confinement boundary, the guard vessel pressure boundary, and the CIA rod sheath to prevent NaK-air and NaK-water reactions that could lead to sodium fires per MARVEL PDCs 71, 73, 74, 78 and 79. The presence of cover gas in the PCS prevents direct contact, while the presence of cover gas within the GVS and CIA rod prevents contact in the event of a leak from the PCS into the respective space.

Derived By: [105328] Reactor Structure Fire Protection, [105320] Cover Gas Supply

Linked From: IGS.4, IGS.5, IGS.3

[117592] Cover Gas Sampling: The IGS shall provide the capability of grab sampling the potentially contaminated cover gas within the PCS.

Rationale: Cover gas sampling helps identify fission product release.

Derived By: [105321] Gaseous Waste Management

Linked From: IGS.6

3.4.1.6 SCGS Functional Requirements

[109378] Helium Supply: The SCGS shall be capable of connecting to and supplying helium gas to the IHX headspace.

Rationale: An inert cover gas is used for chemistry control of the secondary coolant.

Derived By: [105320] Cover Gas Supply

Linked From: SCGS.1, SCGS.2

[117542] Cover Gas Removal from IHX: The SCGS shall be capable of routing potentially contaminated cover gas from the IHX headspaces to the T-REXC ventilation system.

Rationale: Potentially contaminated cover gas must be routed to through the credited and filtered confinement path provided by T-REXC.

Derived By: [105321] Gaseous Waste Management

Linked From: SCGS.3

[117543] Exhaust Sampling: The SCGS shall provide the capability of grab sampling the potentially contaminated cover gas prior to discharge to the T-REXC ventilation system.

Rationale: The potentially contaminated cover gas may be sampled periodically for indication of secondary coolant purity.

Derived By: [105321] Gaseous Waste Management

Linked From: SCGS.4

3.4.1.7 GVS Functional Requirements

[109375] Decay Heat Removal from Primary Coolant: The GVS shall be capable of removing at least 4.8 kWth of heat from the PCS in all modes of operation.

Rationale: The GV forms part of the credited pathway that uses conduction and convection to remove normal and decay heat from the vessel and transfer it to ambient air in the pit.

Derived By: [105316] Heat Transfer to End Users

Linked From: GVS.1

[109376] Decay Heat Transfer to T-REXC: The GVS shall be capable of passively transferring at least 3.2 kWth of heat to the TREAT building atmosphere in all modes of operation.

Rationale: The ultimate heat sink for decay heat is the TREAT building atmosphere.

Derived By: [105316] Heat Transfer to End Users

Linked From: GVS.2

3.4.1.8 UCS Functional Requirements

[115756] UCS Ventilation Pathways for Cooling: The UCS shall provide ventilation pathways to support the removal of an expected 5kW of excess heat during normal operations, maintaining the air temperature below 40ºC.

Rationale: Heat removal protects the Stirling engines and associated components from thermal damage.

Derived By: [105326] Reactor Structure Design for Operating Environment

Linked From: UCS.1

[115757] UCS Leak Management: The UCS System shall prevent escape of potential gas, smoke, or fumes generated by operation or accidents.

Rationale: Penetrations and access holes should be reasonably sealed during normal operations, and fumes should be routed to the T-REXC HEPA filter.

Derived By: [105321] Gaseous Waste Management

Linked From: UCS.3

3.4.1.9 USS Functional Requirements

[115103] Upper Shielding for Equipment: The USS shall limit the radiation received by equipment installed above the upper confinement space to less than a cumulative dose of 1,000 Rad over the lifespan of the reactor.

Rationale: Equipment such as the drum actuators and T-REXC electronics are installed above the upper confinement space and must be protected from degradation. NRC RG 1.209 specifies a limit of 1,000 Rad for metal oxide semiconductor electronics qualified in a radiologically mild environment.

Derived By: [105318] Shielding

Linked From: USS.1

[115102] Upper Shielding for Personnel: The USS shall limit the dose rate on the TREAT high bay floor within 5 feet of the micro-reactor area to less than 200 mrem/hr. while the reactor is in operation.

Rationale: The upper shielding protects personnel in TREAT such that occupational limits are maintained. The numerical value of this requirement is derived from the T-REXC F&OR.

Derived By: [105318] Shielding, [112061] Operating Dose Rate Limit on TREAT Reactor Building High Bay Floor

Linked From: USS.1

3.4.2 Subsystem and Major Components

No unique requirements are applicable to this section at this revision.

3.4.3 Boundaries and Interfaces

No unique requirements are applicable to this section at this revision.

3.4.4 Code of Record

[112247] ASME, "Boiler and Pressure Vessel Code", Section III, Division 5, 2021 Edition.

[117598] ASME, "Boiler and Pressure Vessel Code", Section VIII, 2021 Edition.

Design and construction of the Primary Coolant System (PCS) Pressure Boundary components will meet the ASME Boiler and Pressure Vessel Code, Section III, Division 5, Subsection HB (Code Class A).

Design and construction of the Intermediate Heat Exchanger (IHX) Liner in the Secondary Coolant System (SCS) will meet the ASME Boiler and Pressure Vessel Code, Section VIII.

Design and construction of the Guard Vessel System (GVS) Pressure Boundary Components will meet the ASME Boiler and Pressure Vessel Code, Section III, Division 5, Subsection HC (Code Class B).

3.4.5 Operability

[109388] Waste Heat Loss: The PCS shall be designed to maintain heat loss to the guard vessel annulus beneath 10% at HFP conditions.

Rationale: Losing reactor heat to the ambient air reduces the efficiency of the integrated subsystem and decreases net electrical power output. 10% of reactor full power is still above the required minimum decay heat transfer to the guard vessel, as specified in Section 3.4.1.

Derived By: [105316] Heat Transfer to End Users

Linked From: PCS.1, PCS.3, PCS.4

3.5 Specific Requirements

3.5.1 Radiation and Other Hazards

[109390] Concrete Activation Protection: The SHLD (in combination with the T-REXC pit shielding) shall support the reduction of T-REXC concrete activation such that the dose rate is less than 0.5 mrem/hr at 30cm from the structure 90 days after shutdown of the reactor.

Rationale: Activating the pit concrete will increase the complexity of D&D activities and preclude future use of the T-REXC.

Derived By: [105318] Shielding, [112059] Facility Activation

Linked From: SHLD.1

[109391] Equipment Protection from Activation: The SHLD shall limit neutron activation of equipment in the upper confinement space such that it can be decommissioned and removed from the T-REXC test bed while maintaining personnel exposure ALARA and below the INL established administrative limit.

Rationale: Activated components challenge the D&D of the system. Normal maintenance activities in the area are performed in dose rates of 0.5 mrem/hr. or less and any work performed in greater dose rates would be out of the norm and addressed with job specific controls (RWP/ALARA Review).

Derived By: [112060] Shutdown Dose Rate Limit on TREAT Reactor Building High Bay Floor, [105318] Shielding, [105330] Reactor Structure Decommissioning

Linked From: SHLD.2

[109392] Instrument Protection from Radiation: The SHLD shall provide shielding to limit radiation exposure of reactor control instrumentation to less than 10,000 Rads, cumulative dose.

Rationale: Neutron activation of certain instruments will lead to erroneous readings or equipment failure. This value is based on the range that most generic electronics and Teflon can survive. In other words, the total does over the lifetime is similar to a background field over a longer period of time.

Derived By: [105318] Shielding

Linked From: SHLD.2

[109393] Primary Coolant Boundary Leak Rate: The primary coolant boundary shall maintain an integrated helium leak rate of less than 1 x 10-6 std cc/sec.

Rationale: A low leakage primary coolant boundary is essential for the confinement of radionuclides. The leak rate criterion is derived from ASME BPVC Section V, Article 10 for welded components.

Derived By: [105329] Reactor Structure Fission Product Confinement

Linked From: PCS.5

[109394] Guard Vessel Leak Rate: The guard vessel shall maintain an integrated helium leak rate of less than 1 x 10-4 std cc/sec.

Rationale: The guard vessel forms a confinement boundary and must be leak tight to prevent fission product release. The leak rate criterion is derived from ASME BPVC Section V, Article 10 for mechanical joints.

Derived By: [105329] Reactor Structure Fission Product Confinement

Linked From: GVS.4

3.5.2 As Low As Reasonably Achievable [ALARA]

[109396] TREAT Equipment Dose Rate Limit: The USS in conjunction with T-REXC shielding shall limit the cumulative dose to TREAT electronics-.

Rationale: This ensures sufficient shielding is designed and installed to minimize equipment degradation due to radiation in the areas adjacent to the T-REXC micro reactor area. This requirement is pending the inclusion of a dose limit in a future revision of FOR-684. -

Derived By: [105318] Shielding, [112061] Operating Dose Rate Limit on TREAT Reactor Building High Bay Floor

Linked From: USS.1, SHLD.2

[109397] Shutdown Dose Rate Limit: The SHLD shall limit the dose rate to personnel on the TREAT high bay floor within 5 feet of the T-REXC pit to less than 0.05 mrem/hr and ALARA within 4 hours after reactor shutdown.

Rationale: Limiting the dose rate during shutdown will avoid interference with TREAT operations.

Derived By: [105318] Shielding, [112060] Shutdown Dose Rate Limit on TREAT Reactor Building High Bay Floor

Linked From: SHLD.3

3.5.3 Nuclear Criticality Safety

No unique requirements are applicable to this section at this revision.

3.5.4 Industrial Hazards

[109399] Cover Gas Overpressure Protection: The IGS shall provide a means of overpressure protection for compressed gas distribution equipment.

Rationale: Overpressure protection is required on pressurized gas systems.

Derived By: [105320] Cover Gas Supply

Linked From: IGS.4, IGS.5, IGS.3

[109400] Primary Coolant Thermal Expansion: The PCS shall be capable of accommodating primary coolant expansion of up to 23% by volume from ambient temperature to operating temperature.

Rationale: To prevent subsystem overpressure, the PCS and cover gas subsystem shall accommodate primary coolant expansion from initial startup temperature through operating temperature and maximum accident scenario temperature without exceeding PCS design pressure. The NaK will experience expansion when heated from 25C to the maximum MARVEL coolant temperature of 650C up to 22%.

Derived By: [105326] Reactor Structure Design for Operating Environment, [105329] Reactor Structure Fission Product Confinement

[109401] Guard Vessel Sloping: The guard vessel shall be sloped to a low point capable of retaining leaked primary coolant.

Rationale: A low point in the guard vessel allows leaked NaK to collect in a single area enabling easier and earlier primary coolant leak detection.

Derived By: [105323] Primary Coolant Leak Collection

Linked From: GVS.3

[109402] Primary Coolant Leak into IHX: The leakage of NaK from the PCS into the IHX pressure boundary during a postulated accident, including any generated fumes caused by the reaction, shall be confined to the upper confinement space.

Rationale: A NaK leak should not be able to cause a breach of the subsequent confinement boundary.

Derived By: [105323] Primary Coolant Leak Collection, [105329] Reactor Structure Fission Product Confinement

[109403] Impact of Primary Coolant Leak on Water Lines: The leakage of NaK from the PCS into the IHX pressure boundary during a postulated accident shall not cause breaches of water piping/tubing.

Rationale: A NaK leak into the IHX could result in an increase in the engine cooling water temperature and generate a steam explosion.

Derived By: [115350] Reactor Structure Design for Dynamic Effects

[109194] Engine Helium Leakage into IHX: Accidental leakage of helium from the engine into the IHX pressure boundary shall not cause a subsequent breach of the primary coolant boundary.

Rationale: The high helium pressure in the engine has the potential to rupture structural components if suddenly released. If released into the IHX, the pressure could challenge the primary coolant boundary formed by the bottom of the IHX.

Derived By: [115350] Reactor Structure Design for Dynamic Effects

[109195] Engine Helium Leakage and Secondary Coolant Splattering: The UCS shall confine any splattering of molten secondary coolant.

Rationale: Molten secondary coolant will need to be fully contained in the upper confinement space in the event of a helium leak into the IHX because it has the potential to contain radioactive particles.

Derived By: [115350] Reactor Structure Design for Dynamic Effects

Linked From: UCS.2

[115766] UCS Overpressure Prevention: The UCS and attached ductwork shall be able to withstand pressure release associated with a Stirling engine failure.

Rationale: The ductwork ensures any emitted fumes, smoke, or gas are passed through a HEPA filter prior to release through the stack.

Derived By: [115350] Reactor Structure Design for Dynamic Effects

Linked From: UCS.1, UCS.3

[115767] UCS Impact Resistance: The UCS lid shall resist or avoid damage due to impact caused by potential Stirling engine failure (liftoff).

Rationale: The stirling engine has the potential to fail, causing a sudden release of pressurized gas. This release could challenge the structural integrity of the confinement boundary.

Derived By: [115350] Reactor Structure Design for Dynamic Effects

3.5.5 Operating Environment and Natural Phenomena

[109405] Reactor Structure Seismic Design Criteria: The PCS, RSS, GVS, and SHLD components, as well as the supporting frame for these SSCs, responsible with providing the passive decay heat rejection pathway to the T-REXC shall be designed to the seismic criteria of IBC-2015, using the response coefficients in Table 3-1 of DOE-STD-1020.

Rationale: The MARVEL reactor is categorized as NDC-2 per SDS-119. Per DOE-STD-1020, SDC-1 and SDC-2 SSCs shall be designed according to the criteria of IBC-2015, for Risk Category II and Risk Category IV facilities.

Derived By: [105327] Reactor Structure Seismic Design

Linked From: PCS.6, GVS.5, RSS.1, RSF.1, RSS.2

[109406] Primary Coolant Boundary Temperature Environment: SSCs that form the primary coolant boundary shall be capable of maintaining their structural integrity at temperatures up to 570°C for the duration of the project with excursions to 645°C for no more than 24 hours cumulative.

Rationale: Equipment must be designed to function in the environment in which it is installed, including during temporary accident conditions when the bulk coolant temperature has the potential to reach 645°C. ASME Service Level D calculations consider excursions to 645°C for 30 hours as a one-time credible event. Exceeding this will require re-evaluation.

Derived By: [105326] Reactor Structure Design for Operating Environment, [105329] Reactor Structure Fission Product Confinement

Linked From: PCS.1, PCS.6

[109407] Primary Coolant Boundary Radiation Environment: SSCs that form the primary coolant boundary shall be capable of operating while receiving a lifetime fast neutron fluence (E>1.0MeV) of up to 3.33E20 nvt for the duration of the project.

Rationale: Neutron irradiation has the potential to weaken structural materials.

Derived By: [105329] Reactor Structure Fission Product Confinement, [105326] Reactor Structure Design for Operating Environment

Linked From: PCS.6

[109408] Guard Vessel Pressure Boundary Temperature Environment: SSCs that form the guard vessel pressure boundary shall be capable of maintaining their structural integrity at temperatures up to 565°C for the duration of the project.

Rationale: Equipment must be designed to function in the environment in which it is installed.

Derived By: [105329] Reactor Structure Fission Product Confinement, [105326] Reactor Structure Design for Operating Environment

Linked From: GVS.5

[109409] Guard Vessel Pressure Boundary Radiation Environment: SSCs that form the guard vessel pressure boundary shall be capable of operating while receiving a lifetime fast neutron fluence (E>1.0MeV) of up to 3.33E20 nvt for the duration of the project.

Rationale: Equipment must be designed to function in the environment in which it is installed. These SSCs will not have provisions for maintenance and replacement and therefore must last the duration of the project.

Derived By: [105326] Reactor Structure Design for Operating Environment, [105329] Reactor Structure Fission Product Confinement

Linked From: GVS.5

[109410] Primary Coolant Boundary Overpressure Protection: The PCS shall be designed to withstand a maximum pressure of 55 psig.

Rationale: Equipment must be designed to function in the environment in which it is installed, including during temporary accident conditions when the reactor bulk coolant temperature has the potential to reach 650°C. The maximum pressure is derived from ECAR-6586.

Derived By: [105329] Reactor Structure Fission Product Confinement, [105326] Reactor Structure Design for Operating Environment

Linked From: PCS.6, PCS.5

3.5.6 Human Interface Requirements

No unique requirements are applicable to this section at this revision.

3.5.7 Specific Commitments

No unique requirements are applicable to this section at this revision.

3.6 Engineering Discipline Requirements

3.6.1 Civil and Structural

[109411] Reactor Support: The RSF shall be capable of structurally supporting all dead and live load combinations imparted by the MARVEL reactor during normal operations, anticipated events, and postulated accident conditions.

Rationale: The RSF is responsible for translating the loads from the MRS (except the lower radial SHLD shield) to the T-REXC structure and ensuring that the reactor does not move or tip.

Derived By: [105319] Structural Support for Reactor

Linked From: RSF.1

[109412] Stirling Engine Support: The SOS and SSS shall be designed to support all structural loads (dead and live) of the Stirling engines.

Rationale: The Stirling engines must be suspended in the secondary coolant to produce electricity. Additionally, if the Stirling engines were to fall, they would be damaged and could potentially also weaken or rupture the primary coolant boundary.

Derived By: [105319] Structural Support for Reactor

Linked From: SOS.1, SSS.1

[115100] Drum Actuator Support: The USS shall provide structural support of the drum forcing components installed above the upper confinement structure.

Rationale: The actuators are installed above the upper confinement structure and on top of the shielding. These components are structurally dependent on the shielding.

Derived By: [105319] Structural Support for Reactor

Linked From: USS.3

[109413] Instrumentation Penetrations: The GVS and PCS shall contain sufficient instrumentation wells or penetrations to support the monitoring functions of the Instrumentation and Control System (ICS).

Rationale: Several variables will be monitored in the reactor, including temperature, pressure, neutron counts, etc. Each of these instruments must include a corresponding well or tap to facilitate connection back to the ICS outside the T-REXC.

Derived By: [104520] Instrumentation for Reactor Startup, [104513] Reactor Parameter Monitoring

Linked From: GVS.4

[114209] Reactor Support Frame Space Claim: The RSF shall fit within a 6 ft. W x 6 ft. L x 8 ft. H volume.

Rationale: Demonstration micro-reactors within the T-REXC pit have a 10 ft L × 7 ft W × 9 ft H space constraint. 1 ft. of margin is provided on the width and height dimensions, while 4 ft. of margin on the length allows support equipment to be placed within the pit.

Derived By: [112021] Reactor Area Dimensions

[114210] Reactor Floor Loading: The RSF shall impart a floor loading less than 1000 lbs. per square foot.

Rationale: The floor loading of the pit is established in ECAR-3164, "TREAT Floor Loading Evaluation".

Derived By: [112082] Floor Loading

[115758] UCS Component Access: The UCS shall provide sufficient penetration for components mounted above the USS.

Rationale: Control drum drives, CIA drives, and locks are mounted above the USS.

Derived By: [105332] Reactor Structure Maintenance and Replacement

[115761] UCS Patch Panel: The UCS shall facilitate the penetration of all required cabling and tubing for equipment mounted within the confinement space (i.e. a patch panel).

Rationale: The patch panel maintains the space as a confinement barrier while simultaneous enabling I&C and mechanical pass-throughs.

Derived By: [105332] Reactor Structure Maintenance and Replacement

[115765] UCS Attachment Mechanism: The UCS shall be secured to the top of the PCS in a manner that does not compromise PCS integrity.

Rationale: The attachment of the UCS to the PCS cannot challenge the integrity of the primary coolant boundary.

Derived By: [105319] Structural Support for Reactor

3.6.2 Mechanical and Materials

[109415] Engine Vibration Dampening: The SOS shall isolate the transmission of ±1mm of dynamic motion at frequencies between 60-65Hz from the Stirling engines to the PCS.

Rationale: The Stirling engines connected to the MRS should not impose excessive dynamic stress on the PCS.

Derived By: [105319] Structural Support for Reactor

Linked From: SOS.2

[109416] Noncombustible Materials: MRS components within T-REXC shall be constructed of noncombustible materials to the extent practical.

Rationale: Using noncombustible materials decreases the potential for fires to spread throughout the reactor.

Derived By: [105328] Reactor Structure Fire Protection

[109417] Primary Coolant Thermal Cycling: Stress-strain caused by thermal cycling of the NaK over the operational lifespan of the reactor shall not cause a breach of the primary coolant pressure boundary.

Rationale: Equipment must be designed to function in the environment in which it is installed. The temperature of the primary coolant will oscillate over the lifespan of the reactor depending on the operational mode.

Derived By: [105326] Reactor Structure Design for Operating Environment

[109419] Primary Coolant Corrosion/Erosion: Corrosion and/or erosion by the NaK over the operational lifespan of the reactor shall not cause a breach of the primary coolant pressure boundary, including at the interface with the IHX.

Rationale: Equipment must be designed to function in the environment in which it is installed.

Derived By: [105326] Reactor Structure Design for Operating Environment

[109420] Secondary Coolant Corrosion/Erosion: Corrosion and/or erosion by the secondary coolant over the operational lifespan of the reactor shall not cause a breach of the primary coolant pressure boundary.

Rationale: Equipment must be designed to function in the environment in which it is installed. The secondary coolant has the potential to embrittle the IHX liner due to corrosion and erosion effects.

Derived By: [105326] Reactor Structure Design for Operating Environment

[109421] Guard Vessel Size: The guard vessel shall be sized such that a LOCA into the guard vessel does not result in the core becoming uncovered.

Rationale: The core must remain covered with NaK in the event of a LOCA to preserve the heat transfer pathway to the ultimate heat sink. Differences in overpressure between the PCS and the GVS may impact the settled level of the coolant and should be included in the verification of this requirement.

Derived By: [105323] Primary Coolant Leak Collection, [105317] Decay Heat to Ultimate Heat Sink

3.6.3 Chemical and Process

[109422] Chemical Compatibility of Primary Coolant: The primary coolant shall not chemically react with materials in the fuel cladding, the intermediate heat exchanger, the reactor vessel, and the guard vessel at normal operating and postulated accident conditions.

Rationale: The primary coolant cannot degrade the materials it comes in contact with which would challenge the primary coolant boundary. If the NaK leaks into the guard vessel, it should also be chemically compatible with that material.

Derived By: [105329] Reactor Structure Fission Product Confinement, [105326] Reactor Structure Design for Operating Environment

Linked From: PCS.6

[109423] Chemical Compatibility of Secondary Coolant: The IHX Liner shall protect the IHX and PCS from contact with the secondary coolant.

Rationale: The secondary coolant has the potential to degrade components with which it is in contact. The IHX liner can be replaced as necessary to protect the PCS boundary.

Derived By: [105326] Reactor Structure Design for Operating Environment, [105329] Reactor Structure Fission Product Confinement

[109424] Argon Gas Purity: The IGS shall supply 99.99% pure argon gas.

Rationale: Argon cover gas supplied to the reactor subsystems must be of sufficient purity to avoid corrosion and reaction with NaK. 99.99% purity is derived from previous EBR-II operating experience.

Derived By: [105320] Cover Gas Supply

Linked From: IGS.2

[109425] Primary Coolant Purity: NaK supplied to the primary coolant subsystem shall be of sufficient purity to -prevent chemical interaction with structural materials.

Rationale: The project should minimize the potential for impurity formation within the primary coolant subsystem that can impact the thermal properties of the coolant or cause corrosion to the primary coolant boundary.

Derived By: [105322] Primary Coolant Supply

Linked From: PCMS.2

3.6.4 Electrical Power

This section is not applicable to this system.

3.6.5 Instrumentation and Control

This section is not applicable to this system. Note that while there are control functions associated with the MRS, the performer of these functions is the ICS. The ICS monitors various reactor and system parameters, performs logic solving to determine an output, and then sends control signals to actuating components such as valves, motor drives, etc. to modulate MRS components. See TFR-2574, “MARVEL Instrumentation and Control System (ICS)”, for the majority of reactor control functions.

3.6.6 Computer Hardware and Software

This section is not applicable to this system.

3.6.7 Fire Protection

Other requirements for material selection and NaK reaction prevention using an inert cover gas and containing leaks cover the fire protection requirements of the MRS.

3.7 Testing and Maintenance Requirements

3.7.1 Testability

No unique requirements are applicable to this section at this revision.

3.7.2 Inspections, Testing and Surveillances

Note: Due to the short operational lifespan of the MARVEL reactor, in-service inspections specified in ASME BPVC Section XI will not be required.

3.7.3 Maintenance

[109426] Stirling Engine Removal: The SOS shall allow the removal of a single Stirling engine from the reactor without the need to remove the remaining engines.

Rationale: Replacement of a Stirling engine is anticipated maintenance and should be easy enough to not cause long periods of reactor inoperability. This replacement should not impact the other trains of the PGS.

Derived By: [105332] Reactor Structure Maintenance and Replacement

[109427] IHX Liner Removal: Each SCS IHX liner shall be removable from the greater MRS.

Rationale: All MARVEL components installed in a radiation environment must have a viable D&D strategy at the conclusion of operations.

Derived By: [105330] Reactor Structure Decommissioning

[115759] UCS Lid Removability: The upper lid of the UCS shall be removable.

Rationale: Removal of the UCS lid permits maintenance operations on components installed within the space.

Derived By: [105332] Reactor Structure Maintenance and Replacement

[115762] UCS Patch Panel Accessibility: The inward-facing side of the patch panel shall be accessible.

Rationale: Accessibility permits repairs and maintenance as necessary according to ALARA principles.

Derived By: [105332] Reactor Structure Maintenance and Replacement, [105331] Reactor Structure Inspection and Testing

[115763] UCS Cable Management: The UCS shall provide features for effective interior and exterior cable and tubing management.

Rationale: Effective cable management protects the cables and tubes from damage during operations and maintenance activities, and supports remote maintenance according to ALARA principles.

Derived By: [105332] Reactor Structure Maintenance and Replacement

[115101] Upper Shielding Removability: The USS shall be removable such that the upper confinement space can be accessed using overhead mechanical handling equipment.

Rationale: The Stirling engines are installed within the enclosed upper confinement space and are expected to require removal and replacement during the operational life of the reactor. To access the upper confinement space, the upper shielding must be removable.

Derived By: [105331] Reactor Structure Inspection and Testing, [105332] Reactor Structure Maintenance and Replacement

Linked From: USS.2

3.8 Other Requirements

3.8.1 Security and SNM Protection

This section is not applicable to this system.

3.8.2 Response to Alarms

This section is not applicable to this system.

3.8.3 Special Installation Requirements

[115760] UCS Lid Alignment: The UCS lid shall have alignment mechanisms for component pass-throughs.

Rationale: Pass-throughs for safety-related components must be properly aligned during installation.

Derived By: [105332] Reactor Structure Maintenance and Replacement

3.8.4 Reliability, Availability, and Preferred Failure Modes

No unique requirements are applicable to this section at this revision.

3.8.5 Quality Assurance

The INL Quality Assurance Program is applicable to all activities affecting quality including design, procurement, fabrication, construction, receiving, installation, inspection, testing, and operation activities. More specifically, construction QA requirements will be specified on Form 540.10C, Subcontractor Requirements Manual (SRM) Applicability - Construction. Fabrication QA requirements for INL-performed fabrication will be specified on Form 431.55, Fabrication Services Work Request, as well as associated drawings and referenced specifications. Conformance to technical and quality assurance requirements will be verified by in-process inspections during fabrication, construction, and installation activities. Such inspections will be outlined in the applicable specifications, drawings, and procurement documents including the INL forms noted above. Final acceptance of procured and in-house fabricated components will be accomplished as defined by fabrication work control documents (including drawings and instructions) and procurement documents (including statements of work, specifications, and drawings), as applicable. Final acceptance of assembled systems will be verified through acceptance testing.

Additional verification of MRS components (including ASME Section III and ANSI/AISC N690 components) will be performed through on-site surveillances during fabrication, inspection, and testing activities in accordance with PLN-6907, “Quality Assurance Surveillance Plan for the Fabrication of the Microreactor Applications Research Validation and Evaluation (MARVEL) Project”. INL may also perform source verification of fabricated components (as identified by the applicable procurement specification).

4. APPENDICES

Appendix A, Source Documents

Appendix B, System Drawings and Lists

Appendix A Source Documents

[107769] DOE-STD-1020-2016, "Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities", U.S. Department of Energy, 2016.

FOR-684, “Transient Reactor Test (TREAT) Facility Micro-Reactor Experiment Cell (T-REXC),” Rev. 0, Idaho National Laboratory

FOR-868, “Microreactor Applications Research Validation and Evaluation (MARVEL) Project”, Rev. 0, Idaho National Laboratory.

PDD-13000, “Quality Assurance Program Description”, Rev. 10, Idaho National Laboratory.

SAR-420-ADD-1, “Addendum to Support the Microreactor Applications Testbed,” Rev. 0, Idaho National Laboratory

TFR-2574, “MARVEL Instrumentation and Control System (ICS),” Rev. 0, Idaho National Laboratory

Appendix B System Drawings and Lists

See the Affected Document List in EC-1755 for a full listing of MARVEL MRS drawings.