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TFR-2577 MARVEL Fuel and Core System (FCS)

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Changing the World's Energy Future

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Technical and Functional Requirements

MARVEL Fuel and Core System (FCS)

Idaho National Laboratory

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CONTENTS

1. INTRODUCTION

1.1 System Identification

This document contains the Level 3 requirements associated with the three subsystems of the Fuel and Core System (FCS) in the Microreactor Applications Research Validation and Evaluation (MARVEL) project:

- Fuel Subsystem (FS)
- Core Support Structures Subsystem (CSS)
- Stationary Core Reflector Subsystem (SCR)

These subsystems interface directly with the MARVEL Reactor Structure (MRS) to produce and transfer thermal energy generated through nuclear fission.

1.2 Limitations of the T&FR

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

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 Fuel and Core System is responsible for the overall development and maintenance of the T&FR.

1.4 Definitions/Glossary

Core Region	The area of the reactor that includes neutronically important materials to create and sustain a fission chain reaction, such as nuclear fuel and neutron reflectors.
Neutron Source	A capsule that contains material that interacts to generate free neutrons which are emitted from the capsule.

1.5 Acronyms

ALARA	As Low As Reasonably Achievable
BeO	Beryllium Oxide
BOL	Beginning of Life
CIA	Central Insurance Absorber
COR	Code of Record

CSS	Core Structures Subsystem
ECAR	Engineering, Calculation, and Analysis Report
FCS	Fuel and Core System
FS	Fuel Subsystem
HALEU	High-Assay Low-Enriched Uranium
I&C	Instrumentation and Control
IRF	Inherent Reactivity Feedback
kWth	Kilowatt thermal power
MARVEL	Microreactor Applications Research Validation and Evaluation
MBSE	Model-Based Systems Engineering
MRS	MARVEL Reactor Structure
NSR	Non-Safety Related
NSR-AR	Non-Safety Related with Augmented Requirements
PCB	Primary Coolant Boundary
PCS	Primary Coolant System
PDSA	Preliminary Documented Safety Analysis
RCS	Reactivity Control System
RSS	Reflector Support Subsystem
SCR	Stationary Core Reflector Subsystem
SCS	Secondary Coolant Subsystem
SDD	System Design Description
SR	Safety Related
SSCs	Structures, Systems, and Components
TREAT	Transient Reactor Test Facility
T-REXC	TREAT Facility Micro-Reactor Experiment Cell
UZrH	Uranium-Zirconium Hydride

2. GENERAL OVERVIEW

2.1 System Functions

2.1.1 FS Functions

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

FS.1: Create and Sustain Nuclear Fission Chain Reaction

FS.2: Transfer Heat to Fuel Cladding

FS.3: Provide Neutron Reflection and Moderation

FS.4: Provide Inherent Net Negative Reactivity Feedback

FS.5: Confine Fission Products

FS.6: Maintain Fuel in a Coolable Configuration

2.1.2 CSS Functions

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

CSS.1: Maintain Fuel in a Coolable Configuration

CSS.2: Provide Negative Net Reactivity Feedback

2.1.3 SCR Functions

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

SCR.1: Reflect Neutrons into Core Region

SCR.2: Facilitate Heat Transfer from the PCS to the GVS

SCR.3: Maintain Alignment and Free Rotation of the Control Drums.

SCR.4: Provide Net Negative Reactivity Feedback

2.2 System Classification

The table below provides the classifications for the subsystems of the FCS 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. FCS Subsystem Classifications.

Acronym	Subsystem	Classification
FS	Fuel Subsystem	Safety Related (SR)
CSS	Core Structures Subsystem	SR
SCR	Stationary Core Reflector Subsystem	SR

2.3 Basic Operational Overview

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

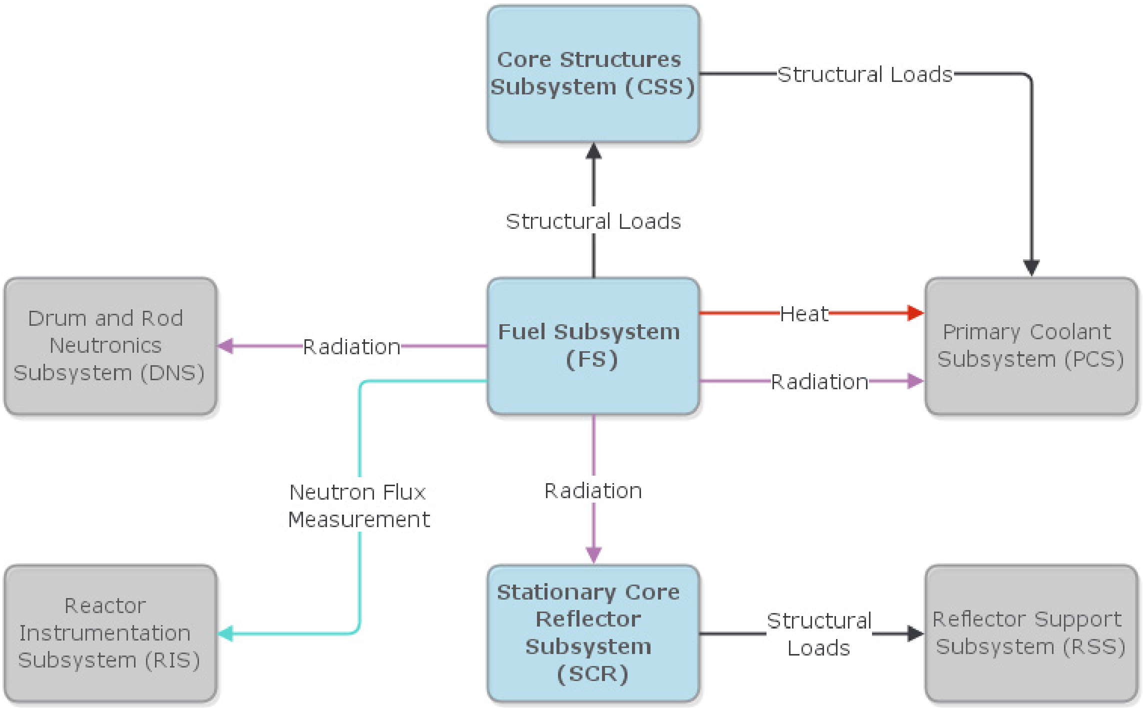

Figure 1. Fuel and Core System Architecture and Interfaces.

2.3.1 FS Basic Operational Overview

The FS is designed to produce a controlled self-sustaining fission chain reaction generating a nominal 85 kWth. The fuel contains high-assay low-enriched uranium (HALEU) enriched to 19.75% and Uranium-Zirconium Hydride (UZrH) as a moderating material. The thermal energy generated by nuclear fission is transferred from the fuel matrix through the cladding to the Primary Coolant Subsystem (PCS). The fuel pin cladding acts as the primary pressure boundary and fission product confinement boundary.

Control of the nuclear chain reaction is accomplished with four control drums during operation. The shutdown of the reactor is accomplished with the control drums and ensured with a central insurance absorber (CIA) rod. These Reactivity Control System (RCS) components are outside the scope of this system– see TFR-2578, "MARVEL Reactivity Control System".

The selected fuel material, UZrH, and the geometry of the fuel-supporting CSS components provide an important safety function known as inherent reactivity feedback (IRF). This means that, by properties of natural physical phenomena, the reactor has multiple sources of self-limiting feedback. As the reactor increases in power and temperature it takes more reactivity to sustain the nuclear chain reaction. This ensures that a positive power feedback loop leading to a runaway power increase cannot physically occur.

The MARVEL microreactor is a high-leakage system. This means that many of the neutrons generated in the core escape the system boundaries due to its small size and the fact that moderation is contained only within the fuel. The fission chain reaction is made possible by the axial and radial neutron reflectors by reducing loss of neutrons from the core due to leakage. The axial neutron reflectors are part of the FS fuel pin.

2.3.2 CSS Basic Operational Overview

Smaller Beryllium radial inserts are provided as part of the CSS within the core region. The assembly of 36 fuel elements into the reactor core is supported inside the reactor vessel by the CSS components. These components hold the fuel elements with the correct spacing to ensure that coolant can flow in all subchannels around the fuel to maintain a coolable core geometry.

2.3.3 SCR Basic Operational Overview

Outside of the primary coolant boundary, additional larger radial Beryllium Oxide (BeO) neutron reflectors are provided as part of the SCR. These reflectors are supported by the Reflector Support Subsystem (RSS). The neutron reflectors also provide some moderation of the neutrons, which assists to increase fission in the core.

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 an 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

[109975] Inherent Reactivity Feedback: The fuel and core support structures shall provide negative reactivity feedback such that the overall reactor provides at least -1.9 pcm of negative reactivity for every °C increase.

Rationale: The MARVEL reactor is designed to limit reactivity transients by means of negative inherent reactivity feedback (IRF). The IRF safety function, via geometric and physics changes, is to promote a system performance that provides a negative reactivity insertion as a function of temperature increase such that the any accidental positive reactivity insertion is passively counteracted and the reactor is brought to new stable state before fuel, clad, and primary coolant boundary (PCB) temperature limits are challenged, or before core damage occurs during anticipated events and postulated accident conditions. Per ECAR-6099, the positive reactivity coefficients accounts for approximately 1.72 pcm/°C. A 10% safety factor is applied to this value to determine the minimum negative reactivity coefficient of the fuel and core.

Derived By: [105342] Fuel and Core Inherent Reactivity Feedback

Linked From: CSS.2, SCR.4, FS.4

[109976] Conduction for Peak Fuel Temperature Limit: The FS shall be designed to conduct heat (including decay heat) from the fuel matrix to the exterior of the cladding such that the peak temperature of the fuel meat does not exceed 900°C in all modes of operation.

Rationale: The fuel centerline temperature directly or indirectly affects the fuel cladding integrity. It must be limited to ensure the integrity of the fuel cladding is not challenged. Eutectic fuel melting has been observed at temperatures above 1050°C per NUREG-1282. The document also imposes a 950°C safety limit if fuel rods are not immersed in coolant, which will be applied to the MARVEL design for conservatism. Additionally, NUREG-1282 has known deficiencies, however INL/RPT-22-68555 Rev 1 confirms the 950°C limit. The original limit of 925ºC was established in this TFR based on maintaining a 25ºC buffer from the limit derived in the references.

During further development of INL/RPT-22-68555 for external presentation, it was determined that the fuel performance analysis was based on a nominal H/Zr ratio of 1.60. The allowable range for fabricated fuel is up to 1.70 where, according to the fuel vendor, fuel whose H/Zr is between 1.65 and 1.70 must be placed at the top or bottom of the fuel element. This additional hydrogen content slightly increases the dissociation pressure, which necessitates a slight reduction in the allowable peak fuel temperature from 925 °C to 900 °C.

Derived By: [105336] Decay Heat Removal Through Reflectors, [105335] Fuel Matrix Heat Transfer

Linked From: FS.2

[109977] Decay Heat Removal from Core Region via SCR: The stationary core reflectors shall facilitate the removal of 1 kW of decay heat from the core region.

Rationale: The SCR and control drums surround the core barrel radially. These components must be designed to allow heat transfer out of the barrel and into the secondary confinement space. The amount of decay heat removal is driven by an unprotected loss of heat sink scenario where reactor heat must be removed via the guard vessel.

Derived By: [105335] Fuel Matrix Heat Transfer

Linked From: SCR.2

[109978] Neutron Reflection: The fuel and stationary core reflectors shall reflect neutrons back into the core and provide neutron moderation to support sufficient core excess reactivity.

Rationale: The natural characteristic of a micro reactor is that the system is small. Neutronically, this creates a core with high leakage. To ensure sufficient reactivity over the life of the core, minimizing neutron leakage is desirable. The FCS will reflect neutrons back into the core to ensure sufficient reactivity with minimal fuel to operate for the design life of the reactor. This function also supports shielding other reactor components from radiation damage. The value of this requirement is derived from ECAR-6099.

Derived By: [105334] Thermal Power Generation

Linked From: FS.3, SCR.1

3.4.2 Subsystem and Major Components

[109979] Neutron Source Strength: A neutron source shall provide a neutron count rate of at least 1/2 counts per second prior to startup, with a signal to noise ratio greater than 2.

Rationale: An external source of neutrons ensures that the point of criticality cannot be passed without initiating the chain reaction or detecting that inflection point. The strength of the neutron source is derived from NRC RG 4.68 Rev 4, Section A-3, "Initial Criticality".

Derived By: [105346] Ex-Vessel Subcriticality, [105334] Thermal Power Generation

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", including Section III, Division 5 and Section VIII, 2021 Edition.

Design and construction of the Core Structures Subsystem (CSS) will meet the ASME Boiler and Pressure Vessel Code, Section III, Division 5, Subsection HG

3.4.5 Operability

[109980] Fuel and Core Removal: All FCS components shall be individually remotely removable from the core region at the end of the reactor operational campaign without needing to remove the reactor from T-REXC.

Rationale: All reactor components must have a viable D&D pathway. At the end of the reactor life, all these components must be removable so that the remainder of the reactor can be disposed of as waste. This removal strategy is a bounding condition of the MARVEL Environmental Assessment contained in LST-1395.

Derived By: [105345] Fuel and Core Decommissioning

3.5 Specific Requirements

3.5.1 Radiation and Other Hazards

[109981] Internal Pressure: The hoop stress in the cladding shall remain below its yield stress in all modes of operation

Rationale: The fuel pin clad is the primary barrier to fission product release. The clad must be sufficiently strong in the operating environment to withstand internal pressure buildup caused by (a) the air originally filing the gas gap during assembly (b) hydrogen that is released from the fuel and (c) fission gases that escape the fuel. The bounding value for internal pressure buildup is derived from the most severe extended beyond design basis accident (BDBA) analyzed in INL/RPT-22-68555.

Derived By: [105343] Fuel and Core Fission Product Confinement

Linked From: FS.6, FS.5

3.5.2 As Low As Reasonably Achievable [ALARA]

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

3.5.3 Nuclear Criticality Safety

[109982] Fuel Pin Loading and Locking: The fuel pin design shall allow the fuel pins to be securely affixed into a fuel subassembly, consisting of no more than 8 individual fuel elements.

Rationale: The fuel will be loaded into the core in subassemblies of multiple rods. The number of fuel elements in a subassembly cannot exceed the administrative handling limit of 8 fuel elements at a time established in the criticality safety evaluation, ECAR-6150. The fuel pin design must allow for the pins to be securely interconnected into a subassembly to prevent fuel pin damage or criticality accidents during fuel loading.

Derived By: [105347] Structural Support for Fuel and Core Equipment, [105346] Ex-Vessel Subcriticality

Linked From: FS.6

3.5.4 Industrial Hazards

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

3.5.5 Operating Environment and Natural Phenomena

[109983] Fuel and Core Seismic Design Criteria: The CSS, and SCR 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 the results of ECAR-5127. 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. Withstanding a seismic event supports the safety function of maintaining a coolable geometry following a postulated accident.

Derived By: [105347] Structural Support for Fuel and Core Equipment, [105339] Fuel and Core Seismic Design

Linked From: CSS.1, FS.6, SCR.3, FS.5

[109984] Core Thermal Environment: Fuel and core SSCs in contact with the primary coolant (e.g., the fuel cladding) shall be capable of maintaining their structural integrity at temperatures up to 800°C in all operating conditions.

Rationale: Equipment must be designed to function in the environment in which it is installed. This requirement supports the function of fission product confinement in that the fuel and core structures will not fail (i.e., melt) at postulated accident temperatures. For the cladding itself (Req No 109984), Article HBB-700: Overpressure Protection of the ASME/BPVC SECTION III DIVISION 5 HIGH TEMPERATURE REACTORS - RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS recommends a temperature limit for 304 stainless steel of 800 °C. Note that this does not mean that the material will be compromised above 800 °C; rather, it means that they haven't codified yield/ultimate stress data above 800 °C for some reason. Since we have to stick with data that is qualified, this is our temperature limit. Note: The maximum permissible clad temperature also may not exceed the saturation temperature of NaK at 1atm of 787°C to prevent localized boiling.

Derived By: [105343] Fuel and Core Fission Product Confinement, [105338] Fuel and Core Design for Operating Environment

Linked From: FS.5

[115376] Core Support Structure Thermal Environment: Core Support SSCs in contact with the primary coolant shall be capable of maintaining their structural integrity at temperatures calculated for normal operations and postulated accident scenarios.

Rationale: Equipment must be designed to function in the environment in which it is installed. This requirement supports the function of fission product confinement in that the fuel and core structures will not fail (i.e., melt) at postulated accident temperatures. For the cladding itself (Req No 109984), Article HBB-700: Overpressure Protection of the ASME/BPVC SECTION III DIVISION 5 HIGH TEMPERATURE REACTORS - RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS recommends a temperature limit for 304 stainless steel of 800 °C. Note that this does not mean that the material will be compromised above 800 °C; rather, it means that they haven't codified yield/ultimate stress data above 800 °C for some reason. Since we have to stick with data that is qualified, this is our temperature limit. Note: The maximum permissible clad temperature also may not exceed the saturation temperature of NaK at 1atm of 787°C to prevent localized boiling.

Derived By: [105338] Fuel and Core Design for Operating Environment

Linked From: FS.5

[109985] Stationary Core Reflector Thermal Environment: The BeO stationary core reflectors shall be capable of maintaining their structural integrity at temperatures up to 650°C.

Rationale: Equipment must be designed to function in the environment in which it is installed, and the temperatures expected near the reactor vessel. In hot full power conditions, the temperature near the reflectors is calculated as 528°C per ECAR-6332. Extra margin is provided in the requirement for conservatism.

Derived By: [105338] Fuel and Core Design for Operating Environment

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

[109987] Stationary Radial Reflectors: The radial reflectors shall be stationary when installed relative to the reactor core.

Rationale: The position of the SCR in relationship to the core is important for reactivity management. The SCR must remain stationary to ensure that core reactivity is stable and sufficient to enable operation of the core over the lifetime of the reactor.

Derived By: [105334] Thermal Power Generation

[109988] Control Drum Clearance: The SCR shall be designed to maintain a clearance of at least 0.18 in. with respect to the control drums at all anticipated operating conditions.

Rationale: Reliable control drum rotation is necessary to ensure sufficient reactivity control of the reactor. The SCR cannot interfere with the control drum rotation and therefore must have adequate clearance. **Derived By:** [105299] Reactivity Control Element Movement

3.6.2 Mechanical and Materials

[109989] Fuel Pin Material: The fuel pin shall utilize a Uranium Zirconium Hydride as its primary fuel.

Rationale: Uranium-zirconium hydride is a well-established, robust fuel with excellent neutronic safety characteristics.

Derived By: [105334] Thermal Power Generation

Linked From: FS.1

[109990] Fuel Uranium Mass Loading: Uranium mass loading shall be within the range of 20-40 wt%, with enrichment of 19.75%.

Rationale: The uranium loading in the uranium-zirconium hydride (UZrH) fuel must be high enough to reach criticality but cannot exceed an upper limit without degrading the fuel characteristics and exceeding the experience base for UZrH fuel. This also ensures that the core has sufficient excess beginning of life (BOL) reactivity to support the MARVEL mission.

Derived By: [105334] Thermal Power Generation, [112094] Facility Safeguards Classification, [105340] Fuel and Core Excess Reactivity

Linked From: FS.1

[109991] Primary Coolant Pressure Drop Mitigation: The core region geometry (FS and CSS) shall be designed to maintain the primary coolant pressure drop across the core at hot full power to less than 180 Pa.

Rationale: MARVEL is a natural convection system. It is important to minimize pressure loss across the core to enable sufficient mass flow of the primary coolant to ensure proper cooling and that fuel clad temperature limits are not challenged. The pressure drop should be equal to the assumed buoyancy head calculated in ECAR-6332.

Derived By: [105336] Decay Heat Removal Through Reflectors, [105335] Fuel Matrix Heat Transfer

Linked From: CSS.1, FS.6

[109992] Material Stress: The core support structures shall be designed in accordance with ASME "Boiler and Pressure Vessel Code", Section III Division 5, subsection HG to withstand material stresses (e.g., creep, swelling) imposed by the operating environment and thermal cycles of the reactor.

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

Derived By: [105338] Fuel and Core Design for Operating Environment

Linked From: FS.6

[109993] Ex-Cladding Gap: The core support structures (grid plates) shall be designed to maintain a uniform fuel cladding to fuel cladding gap of 2mm ± 1.3mm.

Rationale: A uniform ex-cladding gap facilitates adequate flow distribution, fuel cooling, and stable core reactivity to ensure that fuel cladding temperature limits are not challenged. This limit may be updated pending re-analysis for the as-built system.

Derived By: [105336] Decay Heat Removal Through Reflectors, [105335] Fuel Matrix Heat Transfer

Linked From: CSS.1

3.6.3 Chemical and Process

[109994] Cladding Chemical Interactions: The fuel cladding shall have no chemical interaction with internal (i.e., uranium) and external materials (grid plates, primary coolant, etc.) at all postulated operating temperatures of the reactor.

Rationale: A chemical reaction could challenge the ability of the cladding to confine fission products.

Derived By: [105343] Fuel and Core Fission Product Confinement

Linked From: FS.6, FS.5

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.

3.6.6 Computer Hardware and Software

This section is not applicable to this system.

3.6.7 Fire Protection

This section is not applicable to this system.

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

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

3.7.3 Maintenance

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

3.8 Other Requirements

3.8.1 Security and SNM Protection

[109995] Total Core Uranium Mass Loading: The initial core mass loading of U235 shall be less than or equal to 10 kg.

Rationale: This is a DOE agreement to limit the material at risk.

Derived By: [105341] Material at Risk Minimization, [112094] Facility Safeguards Classification

3.8.2 Response to Alarms

This section is not applicable to this system.

3.8.3 Special Installation Requirements

[109996] Lifting Compatibility: The FS shall include lifting features compatible with TREAT facility hoisting equipment.

Rationale: Core components will be installed and removed using lifting mechanisms and therefore must be compatible with this equipment.

Derived By: [105345] Fuel and Core Decommissioning

3.8.4 Reliability, Availability, and Preferred Failure Modes

This section is not applicable to this system.

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 FCS components (including ASME Section III 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

Appendix B System Drawings and Lists

See the Affected Documents List in EC-1759 for a full listing of MARVEL FCS drawings.