INL/MIS-24-78444-Revision-0

FOR-868 Microreactor Applications Research Validation and Evaluation (MARVEL) Project

October 2023

Changing the World's Energy Future

Jack L Blackwell

Idaho National Laboratory

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http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Document ID: FOR-868
Revision ID: 1
Effective Date: 10/03/23

Functional and Operational Requirements

Microreactor Applications Research Validation and Evaluation (MARVEL) Project

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

CONTENTS

1. INTRODUCTION

1.1 Description of Engineering Task

The Microreactor Applications Research Validation and Evaluation (MARVEL) reactor will offer experimental capabilities that are not currently available at DOE's national laboratories. The test bed will perform R&D on the fundamental features, operations, and behaviors of microreactor technologies and help industry partners quickly test, develop, and demonstrate their technologies. The liquid-metal cooled microreactor will produce energy using small amounts of high-assay, low-enriched uranium (HALEU) from available research materials. Its design is primarily based on existing technology and will be built using off-the-shelf components to the extent practical. The reactor will be built inside the Transient Reactor Test (TREAT) Facility Micro-Reactor Experiment Cell (T-REXC), a separate project governed by the requirements of FOR-684, "Transient Reactor Test (TREAT) Facility Micro-Reactor Experiment Cell (T REXC)," and outside the scope of this document.

1.2 Description of the End-Use for the Engineered Item or Activity

The R&D enabled by MARVEL operations include:

- Test, demonstrate, and address issues related to installation, startup, and operation
- Enable Autonomous Operation Technologies
- Enable Seamless Application (power generation, high grade heat extraction, etc.) Integration.

2. OVERVIEW

2.1 Ownership of the F&OR

The owner of this document is the TREAT Engineering Manager.

2.2 End-User of Engineered Item or Activity

The TREAT Facility Manager is the end-user of the completed reactor.

3. ENGINEERING INPUTS

3.1 Background

This document contains the Level I and Level II requirements for the MARVEL project. Level I requirements are the highest-level mission requirements that apply to all structures, systems, and components (SSCs) in the MARVEL design and are derived from unique project objectives. Level II requirements are either derived from regulatory sources (e.g., the MARVEL principal design criteria or DOE Orders & Regulations) or refine/decompose Level I requirements (and are linked to them in the project requirements management database) in terms of how they specifically apply to the 5 primary systems in the MARVEL design:

- Fuel and Core System (FCS)
- MARVEL Reactor Structure (MRS)
- Reactivity Control System (RCS)
- Instrumentation and Control System (ICS)
- Power Generation System (PGS)

The relationship between these systems is shown in the figure below. Grey interfacing systems are outside the scope of the MARVEL project. Red arrows represent thermal interfaces, orange arrows represent electrical interfaces, purple arrows represent nuclear interfaces, teal arrows represent instrumentation and control (I&C) interfaces, and green arrows represent gaseous interfaces.

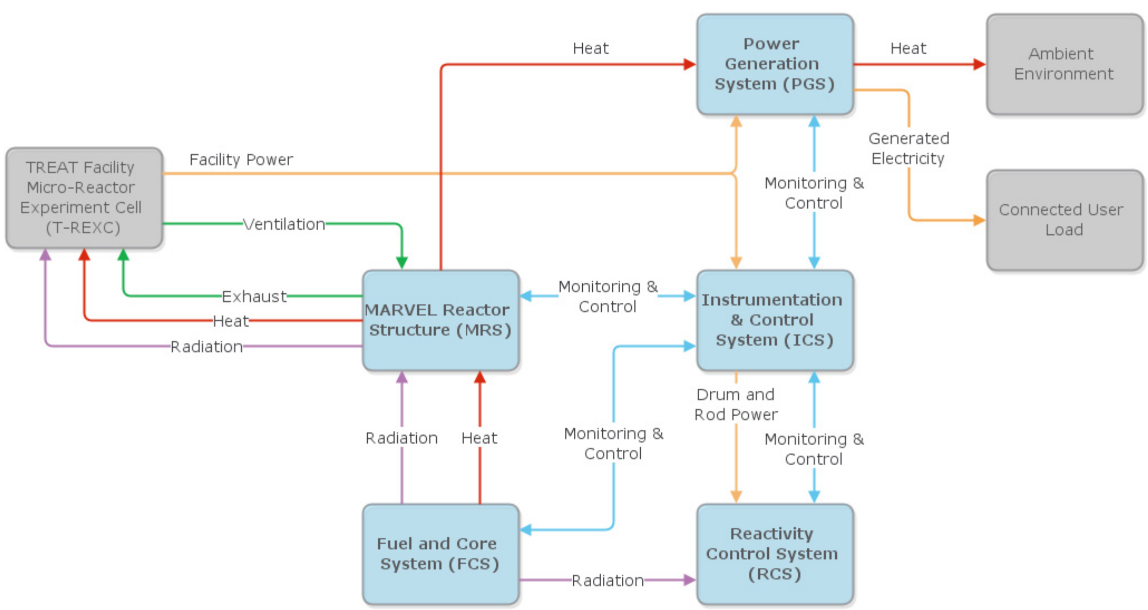

Figure 1 MARVEL Systems and Interfaces

The Level I and Level II requirements in this document derive more detailed Level III requirements found in the technical and functional requirements (T&FR) documents for the project, listed below.

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

TFR-2575, "MARVEL Power Generation System (PGS)," Rev. 0, Idaho National Laboratory

TFR-2576, "MARVEL Reactor Structure (MRS)," Rev. 0, Idaho National Laboratory

TFR-2577, "MARVEL Fuel and Core System (FCS)," Rev. 0, Idaho National Laboratory

TFR-2578, "MARVEL Reactivity Control System (RCS)," Rev. 0, Idaho National Laboratory

Appendix B provides the requirements management philosophy for the project. Appendix C contains a mapping of how all MARVEL principal design criteria and DOE Order 420.1C design requirements are implemented across the T-REXC and MARVEL projects.

A rationale for each requirement is provided to explain where the requirement originates, why it has been adopted by the project, and/or why it provides particular value.

The modes of operation provided in requirements follows the qualitative frequency definitions from MCP-18121, "Safety Analysis Process," including:

- Normal Operations
- Anticipated Events
- Postulated Accident Conditions.

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 traceability 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 so that readers can understand which regulatory requirement the Level II requirement was derived from or which function of the system that the requirement links to/from.

3.2 Level 1 Requirements

[104507] Reactor Startup: MARVEL shall include features necessary to startup the reactor in a safe and controlled manner.

Rationale: One of the primary objectives of the MARVEL program is to demonstrate microreactor startup processes.

[104508] Electricity Generation: The MARVEL reactor shall provide an electrical output suitable for powering various types of electrical loads.

Rationale: To meet the objectives of an applications test reactor, MARVEL has to produce electrical power as an output. The electrical power output is limited by the available reactor thermal power and system efficiencies.

[104509] Manual Control: The MARVEL reactor shall be brought critical and operated using manual control.

Rationale: Executing software quality assurance requirements becomes more extensive as control becomes more complex (as is the case with automated control methods) which increases expense and time consumption. These factors could threaten project schedule and cost.

[104510] Design Life: The MARVEL reactor shall be designed to operate for at least two calendar-years of intermittent operation.

Rationale: The MARVEL project has determined this is sufficient to accomplish the projected MARVEL objectives and can be achieved with available fuels and core structural materials. Operational duty cycles will be established by the project as part of the design process.

3.3 Level 2 Requirements - Instrumentation and Control System (ICS)

The following diagram shows the primary functions of the ICS, each listed after the diagram. Each function is traceable to the functional requirements in this section as displayed by the "Linked From" relationship beneath the requirement rationale. The primary purpose of the ICS is to enable operator control of the reactor via instrumentation, data feedback, and communication between the control room and the final actuating elements.

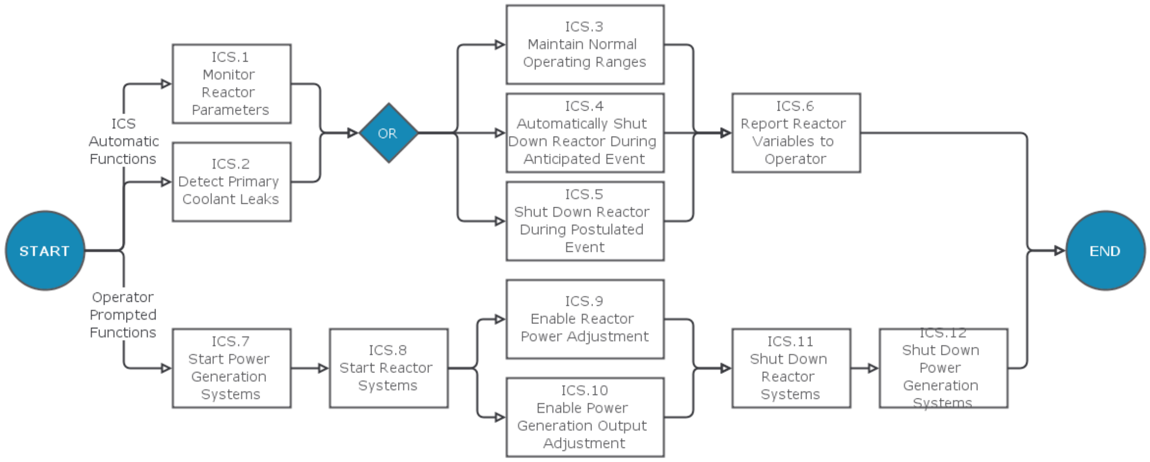

Figure 2 Instrumentation and Control System Functional Diagram

ICS.1: Monitor Reactor Parameters

ICS.2: Detect Primary Coolant Leaks

ICS.3: Maintain Normal Operating Ranges

ICS.4: Automatically Shut Down Reactor During Anticipated Event

ICS.5: Shut Down Reactor During Postulated Event

ICS.6: Report Reactor Variables to Operator

ICS.7: Start Power Generation Systems

ICS.8: Start Reactor Systems

ICS.9: Enable Reactor Power Adjustment

ICS.10: Enable Power Generation Output Adjustment

ICS.11: Shut Down Reactor Systems

ICS.12: Shut Down Power Generation Systems

3.3.1 Level 2 ICS Functional Requirements

[104513] Reactor Parameter Monitoring: The ICS shall monitor reactor variables and systems over their anticipated ranges for normal operation, for anticipated events, and for postulated accident conditions, as appropriate to ensure adequate safety.

Rationale: This requirement supports the nuclear facility defense-in-depth strategy of DOE O 420.1C Attachment 2, Chapter I, Section 3.b.(2)(f)(1) and is based on MARVEL PDCs 13, 32, and 77. Monitoring reactor parameters facilitates manual operation in the control room and supports an in-service inspection program for inaccessible components.

Derived By: [104421] PDC.13: Instrumentation and Control, [107745] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(1), [104455] PDC.77: Inspection of the Intermediate Coolant Boundary, [104439] PDC.32: Inspection of Primary Coolant Boundary

Linked From: ICS.1

[104514] Primary Coolant Leak Detection: Means shall be provided for detecting and, to the extent practical, identifying the location of the source of primary coolant leakage.

Rationale: NaK leak detection must be provided per MARVEL PDCs 30 and 73 to inform the operator of a loss of cooling accident (LOCA). The intent of the requirement is not to explicitly identify which part of the primary coolant boundary leaked, but which location it leaked into.

Derived By: [104437] PDC.30: Quality of Primary Coolant Boundary, [104451] PDC.73: NaK Leakage Detection and Reaction Prevention and Mitigation

Linked From: ICS.2

[104515] System Control for Normal Operating Conditions: The ICS shall have the ability to maintain MARVEL systems within their normal operating ranges.

Rationale: ICS collects operations data from various sensors allocated to different systems. Likewise, it controls actuators allocated to other systems to reduce the burden on the operator. This is required per MARVEL PDCs 10, 13, and 15 and DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(1).

Derived By: [104418] PDC.10: Reactor Design, [107745] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(1), [104423] PDC.15: Primary Coolant System Design, [104421] PDC.13: Instrumentation and Control

Linked From: ICS.3

[104516] Automatic Reactor Shutdown: The ICS shall have the capability to automatically shut down the reactor safely to ensure the fuel design limits are not exceeded during any condition of normal operation or anticipated event.

Rationale: This is required per MARVEL PDCs 10, 15, and 20 and DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(2). An automatic reactor shutdown serves as a defense-in-depth capability during normal operations to ensure the fuel design limits are not exceeded and operational constraints are never exceeded.

Derived By: [104418] PDC.10: Reactor Design, [107746] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(2), [104428] PDC.20: Protection System Functions, [104423] PDC.15: Primary Coolant System Design

Linked From: ICS.4

[104518] Postulated Accident Scram: The ICS shall initiate a reactor scram under postulated accident conditions.

Rationale: This is required per MARVEL PDC 20 and DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(3), which states that the MARVEL design must sense accident conditions and initiate the operation of systems and components important to safety.

Derived By: [104428] PDC.20: Protection System Functions, [107747] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(3)

Linked From: ICS.5

[104517] Operator Communication: The ICS shall provide data from monitored parameters to the control room, including those parameters necessary for post-accident monitoring.

Rationale: The operators in the TREAT control room will need to be informed of the reactor status during operation in order to facilitate manual control. This supports post-accident monitoring stipulated in DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(4).

Derived By: [104509] Manual Control, [107748] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(4)

Linked From: ICS.6

[104519] Power Generation Startup: The ICS shall provide the capability to start power generation equipment safely and in a controlled fashion when prompted by an operator.

Rationale: Manual control is a desired capability for the MARVEL reactor. To begin power generation, the power conversion equipment must be brought online.

Derived By: [104507] Reactor Startup, [104509] Manual Control

Linked From: ICS.7

[104520] Instrumentation for Reactor Startup: The ICS shall provide the instrumentation necessary to start the reactor safely and in a controlled fashion by an operator using manual control.

Rationale: Manual control is a desired capability for the MARVEL reactor. To begin power generation, the reactor must first be brought critical. A goal of the MARVEL program is to develop the startup methodology for microreactors.

Derived By: [104507] Reactor Startup

Linked From: ICS.8

[104521] Reactor Power Level Control: The ICS shall provide the capability to change the reactor power safely and in a controlled fashion based on the input from an operator, while limiting the potential amount and rate of reactivity increase.

Rationale: Manual control is a desired capability for the MARVEL reactor. The reactor must be stable enough to be controlled by humans. This control must also limit the amount and rate of reactivity increase per MARVEL PDC 28.

Derived By: [104435] PDC.28: Reactivity Limits, [104509] Manual Control

Linked From: ICS.9

[104522] Power Generation Output Control: The ICS shall provide the capability to change the power generation output level safely and in a controlled fashion based on the input from an operator.

Rationale: Manual control is a desired capability for the MARVEL reactor. The operator should be able to choose the electrical power output of the system.

Derived By: [104509] Manual Control

Linked From: ICS.10

[104523] Reactor Shutdown: The ICS shall provide the capability to shut down the reactor safely and in a controlled fashion when initiated by an operator.

Rationale: Manual control is a desired capability for the MARVEL reactor. The operator shall be able to initiate a shutdown at any time.

Derived By: [104509] Manual Control

Linked From: ICS.11

[104524] Power Generation Shutdown: The ICS shall have the capability to shut down power generation equipment in a controlled fashion when initiated by an operator.

Rationale: Power conversion equipment shutdown is a basic desirable control function and ensures that the conversion equipment stays in sync with the reactor systems.

Derived By: [104509] Manual Control

Linked From: ICS.12

3.3.2 Level 2 ICS Operational Requirements

[104525] Instrumentation and Control Design for Operating Environment: ICS SSCs within the secondary confinement boundary (guard vessel) shall be constructed of materials designed to withstand the credited environmental conditions (e.g., temperature, pressure, radiation, etc.) in which they are installed for at least 2 calendar years of operation without maintenance.

Rationale: Equipment must be designed in consideration of the operating environment per MARVEL PDC 4. This does not include the RCS and PGS components that will be designed to accommodate replacement and repair.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis, [107760] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [104510] Design Life

[104526] Instrumentation and Control Seismic Design: ICS SSCs important to safety shall be designed to withstand the effects of seismic events without the loss of the capability to perform their safety functions.

Rationale: A seismic event cannot challenge the ability of the ICS to perform its safety functions per MARVEL PDCs 2 and 22 and DOE O 420.1C Attachment 2 Chapter IV Section 3.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena, [107752] DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c, [104430] PDC.22: Protection System Independence

[104527] Instrumentation and Control Fail Safe State: ICS SSCs important to safety shall be designed to fail into a safe state.

Rationale: MARVEL is designed to be inherently safe in order to meet MARVEL PDC 23 and DOE O 420.1C, Attachment 3, Section 3.a.(3) requirements for safe failure modes.

Derived By: [104431] PDC.23: Protection System Failure Modes, [107754] DOE O 420.1C Attachment 3 Section 3.a.(3)

[104780] Instrumentation and Control Single Failure Criterion: Active ICS SSCs important to safety shall be designed to meet the single failure criterion defined in IEEE 379.

Rationale: The single failure criterion is required per MARVEL PDCs 21, 22, 25, and 29 and DOE O 420.1C, which invokes the definition of the single failure criterion in IEEE 379 unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-Standard (STD)-1189-2016.

Derived By: [104429] PDC.21: Protection System Reliability and Testability, [107757] DOE O 420.1C Attachment 3 Section 3.a.(2)(a), [107732] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(7), [104436] PDC.29: Protection Against Anticipated Operational Occurrences, [104433] PDC.25: Protection System Requirements for Reactivity Control Malfunctions, [104430] PDC.22: Protection System Independence

[104781] Independence from Control System: The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system.

Rationale: This requirement is derived from MARVEL PDCs 24 and 29, DOE O 420.1C Attachment 3 Section 3.a.(4) and ensures that protection system functions are independent of the normal control system.

Derived By: [104432] PDC.24: Separation of Protection and Control Systems, [107759] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [107755] DOE O 420.1C Attachment 3 Section 3.a.(4), [104436] PDC.29: Protection Against Anticipated Operational Occurrences

[104782] Instrumentation and Control SR Qualification: Safety related (SR) ICS SSCs must be designed to perform all safety functions with no failure mechanism that could lead to common cause failures under postulated service conditions in accordance with IEEE 323-2003 (R2008).

Rationale: Equipment must be designed in consideration of the operating environment per DOE O 420.1C Attachment 3 Section 3.a.(2)(a). IEEE 323 must be used unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-STD-1189-2016. The environmental qualification will be performed per IEEE 627.

Derived By: [107758] DOE O 420.1C Attachment 3 Section 3.a.(2)(a)

[104783] Instrumentation Decommissioning: ICS components shall be designed to facilitate decommissioning.

Rationale: Components installed in the radiation field of the reactor will need to be disposed of as solid radioactive waste. Provisions for D&D are required per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a).

Derived By: [107742] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a)

[104784] Instrumentation and Control Fire Protection: ICS SSCs important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions, consistent with DOE-STD-1066.

Rationale: This requirement is based on MARVEL PDC 3. Noncombustible and fire-resistant materials should be used wherever practical throughout the unit.

Derived By: [104415] PDC.03: Fire Protection, [107756] DOE O 420.1C Attachment 3 Section 3.a.(5)

3.3.3 Level 2 ICS Maintenance Requirements

[104785] Instrumentation and Control Inspection and Testing: Normally accessible ICS SSCs important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features.

Rationale: This is required per MARVEL PDCs 18 and 21 and DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b). SSCs include wiring, insulation, connections, and switchboards, etc. to assess the continuity of the systems and the condition of their components. The systems should be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among systems.

Derived By: [104429] PDC.21: Protection System Reliability and Testability, [107743] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b)

[104786] Instrumentation and Control Maintenance and Replacement: Accessible ICS system equipment shall include provisions for maintenance and removal/replacement while minimizing radiation dose to personnel to the extent practical (ALARA).

Rationale: If I&C equipment fails it should be able to be replaced and returned to service while ensuring worker doses are ALARA. This does not include instruments installed inside the reactor.

Derived By: [104510] Design Life

3.4 Level 2 Requirements - Reactivity Control System (RCS)

The following diagram shows the primary functions of the RCS, each listed after the diagram. Each function is traceable to the functional requirements in this section. The primary purpose of the RCS is to take control signals/requests from the ICS, translate those control signals into mechanical motion, and either add or remove reactivity to/from the fission process via reactivity control elements.

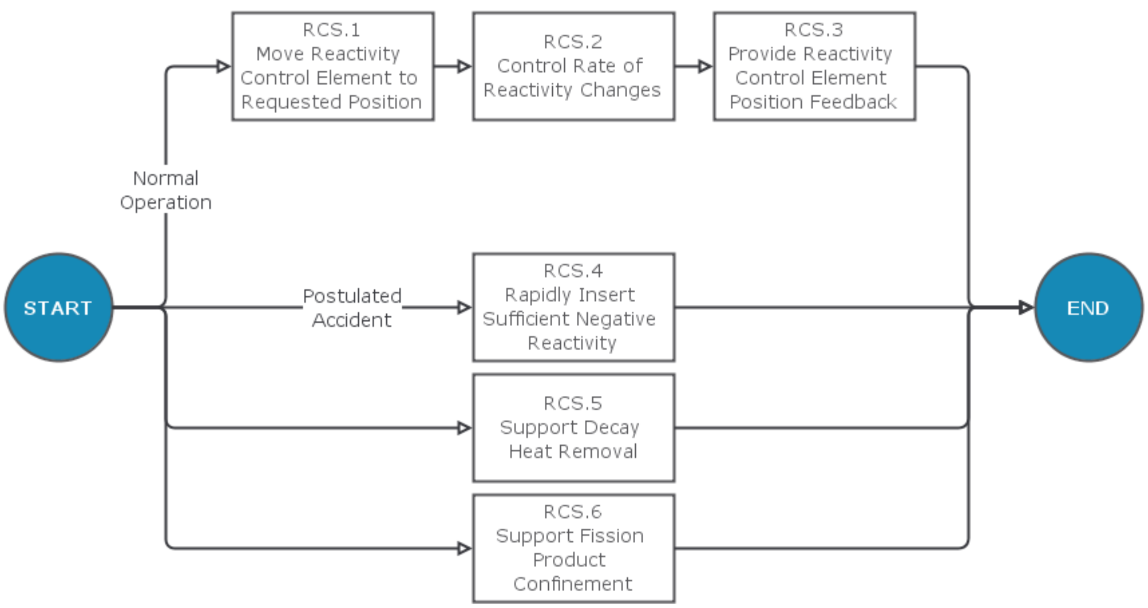

Figure 3 Reactivity Control System Functional Diagram

RCS.1: Move Reactivity Control Element to Requested Position

RCS.2: Control Rate of Reactivity Changes

RCS.3: Provide Reactivity Control Element Position Feedback

RCS.4: Rapidly Insert Sufficient Negative Reactivity

RCS.5: Support Decay Heat Removal

RCS.6: Support Fission Product Confinement

3.4.1 Level 2 RCS Functional Requirements

[105299] Reactivity Control Element Movement: The RCS shall be capable of moving reactivity control elements to the operator-requested position.

Rationale: The RCS serves as the final actuator for reactivity control and must translate operator command signals into reactivity insertion or removal.

Derived By: [104509] Manual Control

Linked From: RCS.1

[105300] Reactivity Change Control: The RCS shall control the rate of reactivity changes resulting from planned, normal power changes to ensure design limits for the fission product barriers are not exceeded.

Rationale: This ensures that the effects of postulated reactivity accidents can neither (1) result in damage to the primary coolant boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor vessel internals to significantly impair the capability to cool the core. This requirement is derived from MARVEL PDCs 12, 26, and 28.

Derived By: [104420] PDC.12: Suppression of Reactor Power Oscillations, [104435] PDC.28: Reactivity Limits, [104434] PDC.26: Reactivity Control

Linked From: RCS.2

[105301] Reactivity Control Element Position Indication: The RCS shall be capable of providing reactivity control element position indication.

Rationale: Position indication lets the operator know whether the system is operating as intended.

Derived By: [104509] Manual Control

Linked From: RCS.3

[105302] Negative Reactivity: The RCS shall provide sufficient negative reactivity to shut down the reactor and maintain it in a safe condition following a normal shutdown or SCRAM.

Rationale: The RCS is responsible for providing the final reactivity control elements. This requirement is derived from MARVEL PDC 26.

Derived By: [104434] PDC.26: Reactivity Control

Linked From: RCS.4

[105303] Decay Heat Removal Through Reactivity Control Elements: The RCS shall facilitate decay heat removal in all operating scenarios, with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: Decay heat will need to be removed following shutdown or scram. The fuel design limits need to be protected in this scenario. This requirement satisfies MARVEL PDCs 34 and 44. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104440] PDC.34: Core Flow/Heat Removal, [107753] DOE O 420.1C Attachment 3 Section 3.a.(1)

Linked From: RCS.5

[113979] Reactivity Control Fission Product Confinement: The RCS shall provide barriers that prevent or mitigate the release of radioactive materials from the reactor to the public and the environment during normal operations, anticipated events, and postulated accident conditions.

Rationale: The integrated MARVEL structure provides radiological confinement to meet MARVEL PDC 16, and DOE O 420.1C Attachment 2 Chapter I Sections 3.b.(2)(e) and Section 3.b.(3)(a).

Derived By: [104424] PDC.16: Confinement of Radioactive Material, [107738] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(e), [107739] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(a)

Linked From: RCS.6

3.4.2 Level 2 RCS Operational Requirements

[105304] Reactivity Control Design for Operating Environment: Inaccessible RCS SSCs shall be constructed of materials designed to withstand the credited environmental conditions (e.g., temperature, pressure, radiation, etc.) in which they are installed for at least 2 calendar years of operation without maintenance.

Rationale: Equipment must be designed in consideration of the operating environment, per MARVEL PDC 4. This does not include equipment that is accessible in the upper confinement space.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis, [107760] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [104510] Design Life

[105305] Reactivity Control Seismic Design: RCS SSCs important to safety shall be designed to withstand the effects of seismic events without the loss of the capability to perform their safety functions.

Rationale: A seismic event cannot challenge the ability of the RCS to perform its safety functions per MARVEL PDCs 2 and 22 and DOE O 420.1C Attachment 2 Chapter IC Section 3.a.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena, [107752] DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c, [104430] PDC.22: Protection System Independence

[105306] Reactivity Control Fail Safe State: RCS SSCs important to safety shall be designed to fail into a safe state.

Rationale: MARVEL is designed to be inherently safe in order to meet MARVEL PDC 23 and DOE O 420.1C, Attachment 3, Section 3.a.(3) requirements for safe failure modes.

Derived By: [104431] PDC.23: Protection System Failure Modes, [107754] DOE O 420.1C Attachment 3 Section 3.a.(3)

[105307] Reactivity Control Single Failure Criterion: Active RCS SSCs important to safety shall be designed to meet the single failure criterion defined in IEEE 379.

Rationale: The single failure criterion is required per MARVEL PDCs 21, 22, and 25 and DOE O 420.1C, which invokes the definition of the single failure criterion in IEEE 379 unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-Standard (STD)-1189-2016.

Derived By: [104429] PDC.21: Protection System Reliability and Testability, [107757] DOE O 420.1C Attachment 3 Section 3.a.(2)(a), [107732] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(7), [104433] PDC.25: Protection System Requirements for Reactivity Control Malfunctions, [104430] PDC.22: Protection System Independence

[105308] Reactivity Control for Startup: The RCS shall include the features and worth to bring MARVEL to the state of sustained nuclear reaction.

Rationale: The RCS elements are responsible for providing the final components for overall reactivity control.

Derived By: [104507] Reactor Startup

[105309] Reactivity Control Element Decommissioning: RCS components shall be designed to facilitate decommissioning.

Rationale: All lifecycle stages should be considered in the design phase. Provisions for D&D are required per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a).

Derived By: [107742] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a)

[105310] Reactivity Control SR Qualification: Safety related (SR) RCS SSCs must be designed to perform all safety functions with no failure mechanism that could lead to common cause failures under postulated service conditions in accordance with IEEE 323-2003 (R2008).

Rationale: Equipment must be designed in consideration of the operating environment per DOE O 420.1C Attachment 3 Section 3.a.(2)(a). IEEE 323 must be used unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-STD-1189-2016.

Derived By: [107758] DOE O 420.1C Attachment 3 Section 3.a.(2)(a)

[105311] Structural Support for Reactivity Control Elements: The RCS shall provide structural support for internal reactivity control element SSCs.

Rationale: The reactivity control elements are supported as an integrated system by the MRS but internal components such as plates and discs will need structural support from other RCS components.

Derived By: [104428] PDC.20: Protection System Functions, [104414] PDC.02: Design Bases for Protection Against Natural Phenomena

3.4.3 Level 2 RCS Maintenance Requirements

[105312] Reactivity Control Inspection and Testing: Normally accessible RCS SSCs important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features.

Rationale: This is required per MARVEL PDC 21. SSCs include wiring, insulation, connections, and switchboards, etc. to assess the continuity of the systems and the condition of their components. The systems should be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among systems.

Derived By: [104429] PDC.21: Protection System Reliability and Testability, [107743] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b)

[105313] Reactivity Control Maintenance and Replacement: Accessible RCS system equipment shall include provisions for maintenance and removal/replacement while minimizing radiation dose to personnel to the extent practical (ALARA) and ensuring the reactor remains shut down.

Rationale: Where possible, the mean time before failure (MTBF) of these components should be more than 2 years. However, components will be designed/selected for ease of replacement in the event of failure.

Derived By: [104510] Design Life

3.5 Level 2 Requirements - MARVEL Reactor Structure (MRS)

The following diagram shows the primary functions of the MRS, each listed after the diagram. Each function is traceable to the functional requirements in this section. The primary purpose of the MRS is to facilitate the heat transfer from the core region to the secondary coolant so that it can eventually be used for power generation. Concurrently, the system removes excess and decay heat from the primary coolant boundary and transfers it to the TREAT reactor experiment cell. The MRS also provides structural support for other MARVEL systems and shielding for co-located workers and TREAT facility equipment. The system includes all functions related to managing cover gas supply and exhaust, primary coolant supply and draining, and secondary coolant supply and draining.

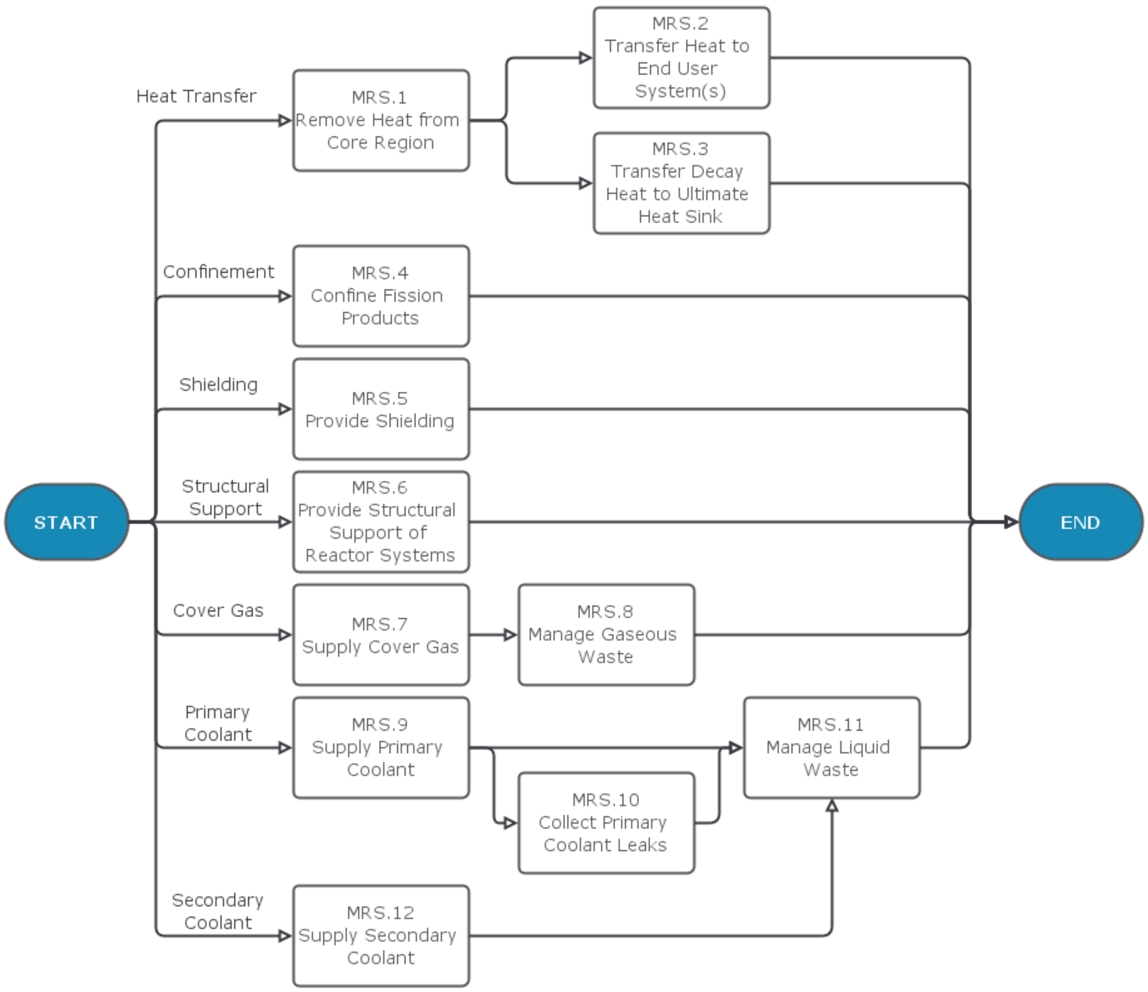

Figure 4 MARVEL Reactor Structure Functional Diagram

MRS.1: Remove Heat from Core Region

MRS.2: Transfer Heat to End User System(s)

MRS.3: Transfer Decay Heat to Ultimate Heat Sink

MRS.4: Confine Fission Products

MRS.5: Provide Shielding

MRS.6: Provide Structural Support of Reactor Systems

MRS.7: Supply Cover Gas

MRS.8: Manage Gaseous Waste

MRS.9: Supply Primary Coolant

MRS.10: Collect Primary Coolant Leaks

MRS.11: Manage Liquid Waste

MRS.12: Supply Secondary Coolant

3.5.1 Level 2 MRS Functional Requirements

[105315] Core Heat Removal: The MRS shall remove heat from the core region with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: Thermal heat produced in the core must be transferred to the naturally circulating primary coolant to meet MARVEL mission objectives. The system must also be able to remove heat from the core to prevent fuel melting/failure per MARVEL PDCs 10, 15, and 44. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104418] PDC.10: Reactor Design, [107753] DOE O 420.1C Attachment 3 Section 3.a.(1), [104508] Electricity Generation, [104441] PDC.44: Structural and Equipment Cooling, [104423] PDC.15: Primary Coolant System Design

Linked From: MRS.1

[105316] Heat Transfer to End Users: The MRS shall facilitate the transfer of heat to end user system(s).

Rationale: Heat in the primary coolant must be transferred out of the reactor to power generation or high grade heat extraction equipment to meet MARVEL mission objectives.

Derived By: [104508] Electricity Generation

Linked From: MRS.2

[105317] Decay Heat to Ultimate Heat Sink: The MRS shall transfer decay heat to the ultimate heat sink in all operating scenarios, with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: Decay heat will need to be removed following shutdown or scram. The fuel design limits need to be protected in this scenario. This requirement satisfies MARVEL PDCs 34 and 44. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104440] PDC.34: Core Flow/Heat Removal, [107753] DOE O 420.1C Attachment 3 Section 3.a.(1), [104441] PDC.44: Structural and Equipment Cooling

Linked From: MRS.3

[105329] Reactor Structure Fission Product Confinement: The MRS shall provide barriers that prevent or mitigate the release of radioactive materials from the reactor to the public and the environment during normal operations, anticipated events, and postulated accident conditions.

Rationale: The MARVEL structure provides radiological confinement to meet MARVEL PDC 16, and DOE O 420.1C Attachment 2 Chapter I Sections 3.b.(2)(e) and Section 3.b.(3)(a).

Derived By: [104424] PDC.16: Confinement of Radioactive Material, [107739] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(a), [107738] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(e)

Linked From: MRS.4

[105318] Shielding: The MRS shall include means to protect reactor components, T-REXC equipment, and TREAT personnel from exposure to radiation.

Rationale: Radiation is harmful to life and physical protection of SSCs is required for reliability and proper function of MARVEL. Shielding is required per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(c).

Derived By: [107744] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(c)

Linked From: MRS.5

[105319] Structural Support for Reactor: The MRS shall provide structural support to all MARVEL SSCs within the T-REXC.

Rationale: Other system's components will we attached to the MRS: RCS motor shafts, Stirling engines, etc.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena

Linked From: MRS.6

[105320] Cover Gas Supply: The MRS shall provide pure cover gas to locations separated from the primary coolant by a single passive barrier.

Rationale: Cover gas is required per MARVEL PDCs 71, 73, 74, 78, and 79 to prevent the primary coolant from contact with oxygen.

Derived By: [104450] PDC.71: Primary Coolant and Cover Gas Purity Control, [104457] PDC.79: Cover Gas Inventory Maintenance, [104456] PDC.78: Primary Coolant System Interfaces, [104452] PDC.74: NaK/Water Reaction Prevention/Mitigation, [104451] PDC.73: NaK Leakage Detection and Reaction Prevention and Mitigation

Linked From: MRS.7

[105321] Gaseous Waste Management: The MRS shall include means to control the compliant release of radioactive materials in gaseous form such that the air emission limits do not exceed those established by T-REXC.

Rationale: The reactor must have gaseous waste management capabilities per MARVEL PDCs 60 and 71.

Derived By: [104444] PDC.60: Control of Releases of Radioactive Materials to the Environment

Linked From: MRS.8

[105322] Primary Coolant Supply: The MRS shall provide pure primary coolant to the primary coolant boundary.

Rationale: Primary coolant is necessary to facilitate heat transfer from the core region.

Derived By: [104450] PDC.71: Primary Coolant and Cover Gas Purity Control

Linked From: MRS.9

[105323] Primary Coolant Leak Collection: The MRS shall include the means to collect leaked primary coolant such that exposure to air, water, or concrete is prevented.

Rationale: NaK reaction with air, water, and concrete (containing water) has the potential to ignite a fire. Leak collection supports MARVEL PDCs 73, 74, and 78.

Derived By: [104451] PDC.73: NaK Leakage Detection and Reaction Prevention and Mitigation, [104456] PDC.78: Primary Coolant System Interfaces, [104452] PDC.74: NaK/Water Reaction Prevention/Mitigation

Linked From: MRS.10

[105324] Liquid Waste Management: The MRS shall include means to control the compliant release of radioactive materials in liquid form.

Rationale: The reactor must have liquid waste management capabilities per MARVEL PDC 60.

Derived By: [104444] PDC.60: Control of Releases of Radioactive Materials to the Environment

Linked From: MRS.11

[105325] Secondary Coolant Supply: The MRS shall provide pure secondary coolant to the secondary coolant system.

Rationale: Secondary coolant is necessary to facilitate heat transfer from the primary coolant to the power generation equipment.

Derived By: [104508] Electricity Generation

Linked From: MRS.12

3.5.2 Level 2 MRS Operational Requirements

[105326] Reactor Structure Design for Operating Environment: Inaccessible MRS SSCs shall be constructed of materials designed to withstand the credited environmental conditions (e.g., temperature, pressure, radiation, etc.) in which they are installed for at least 2 calendar years of operation without maintenance.

Rationale: Features of the MARVEL reactor structure must be rated to withstand their credited operating conditions, per MARVEL PDCs 4, 14, 31, 70, 76, and 77 for the duration of the mission.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis, [107760] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [104510] Design Life, [104455] PDC.77: Inspection of the Intermediate Coolant Boundary, [104454] PDC.76: Fracture Prevention of the Intermediate Coolant Boundary, [104453] PDC.75: Quality of the Intermediate Coolant Boundary, [104449] PDC.70: Intermediate Coolant System, [104438] PDC.31: Fracture Prevention of Primary Coolant Boundary, [104422] PDC.14: Primary Coolant Boundary

[115350] Reactor Structure Design for Dynamic Effects: MRS SSCs important to safety shall be appropriately protected against dynamic effects associated with their installed location.

Rationale: Protection from dynamic effects (i.e., events above and beyond environmental conditions such as temperature, pressure, radiation, etc.) is required per MARVEL PDC 4. The PDC clarifies that dynamic effects include things such as missiles, pipe whipping, and discharging fluids that may result from equipment failures.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis

[105327] Reactor Structure Seismic Design: The MRS shall be capable of withstanding seismic design category (SDC)-2 events without damage to safety SSCs.

Rationale: The reactor structure must be designed to maintain structural stability during seismic events that could challenge the ability to remove heat from the core per MARVEL PDC 2 and DOE O 420.1C Attachment 2 Chapter IV Section 3.a.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena, [107752] DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c

[105328] Reactor Structure Fire Protection: MRS SSCs important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions, consistent with DOE-STD-1066.

Rationale: This requirement is based on MARVEL PDC 3. Noncombustible and fire-resistant materials should be used wherever practical throughout the unit.

Derived By: [104415] PDC.03: Fire Protection, [107756] DOE O 420.1C Attachment 3 Section 3.a.(5)

[105330] Reactor Structure Decommissioning: The MRS shall have features to enable extraction and transportation of activated components outside the TREAT building.

Rationale: D&D must be considered in the design of MARVEL systems. Provisions for D&D are required per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a). The MARVEL reactor will be removed from the TREAT facility at the end of life per Section 2.10 of DOE/EA-2146, Final Environmental Assessment for the Microreactor Applications Research, Validation, and Evaluation (MARVEL) Project at Idaho National Laboratory.

Derived By: [107742] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a)

3.5.3 Level 2 MRS Maintenance Requirements

[105331] Reactor Structure Inspection and Testing: Normally accessible MRS SSCs important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features.

Rationale: This is required per MARVEL PDCs 45, 46, and 61 and DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b).

Derived By: [104442] PDC.45: Inspection of Structural and Equipment Cooling Systems, [107743] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b), [104445] PDC.61: Fuel Storage and Handling and Radioactivity Control, [104443] PDC.46: Testing of Structural and Equipment Cooling Systems

[105332] Reactor Structure Maintenance and Replacement: Accessible MRS system equipment shall include provisions for maintenance and removal/replacement while minimizing radiation dose to personnel to the extent practical (ALARA).

Rationale: Ideally the mean time before failure (MTBF) of these components will be more than 2 years. However, in case of failure they should be designed/selected for ease of replacement.

Derived By: [104510] Design Life

3.6 Level 2 Requirements - Fuel and Core System (FCS)

The following diagram shows the primary functions of the FCS, each listed after the diagram. Each function is traceable to the functional requirements in this section. The primary purpose of the FCS is to produce thermal power via fission and transfer this heat from fuel pins into the core region.

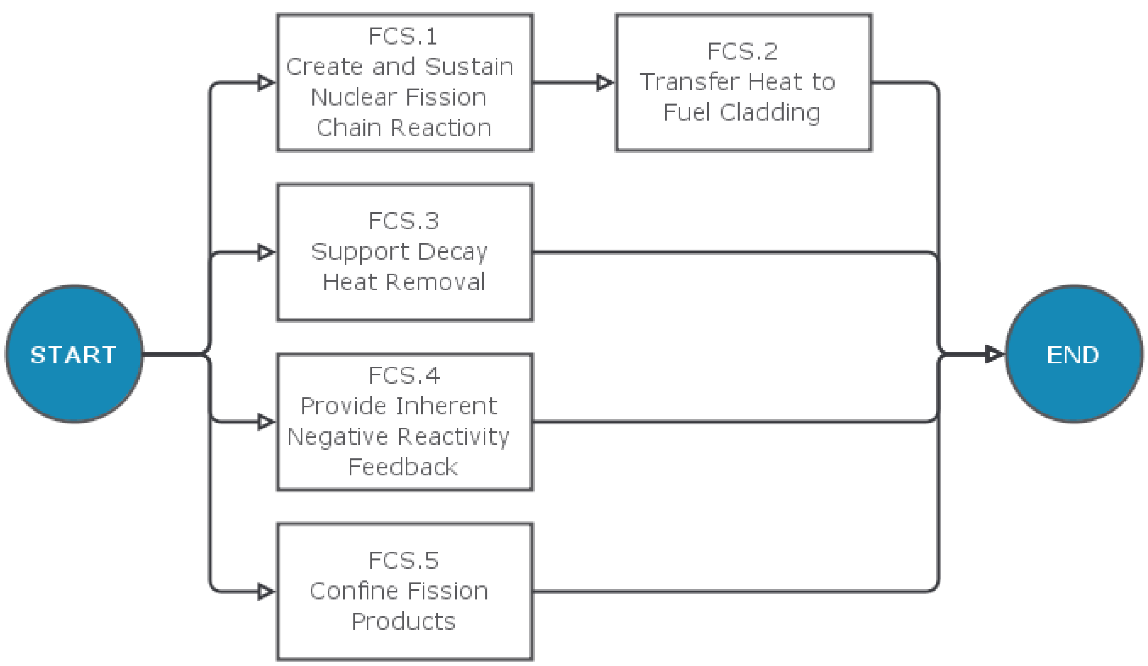

Figure 5 Fuel and Core System Functional Diagram

FCS.1: Create and Sustain Nuclear Fission Chain Reaction

FCS.2: Transfer Heat to Fuel Cladding

FCS.3: Support Decay Heat Removal

FCS.4: Provide Inherent Negative Reactivity Feedback

FCS.5: Confine Fission Products

3.6.1 Level 2 FCS Functional Requirements

[105334] Thermal Power Generation: The FCS shall be designed to generate thermal power via sustained nuclear fission.

Rationale: MARVEL must provide electrical power as an output. In order to produce electrical power, thermal power needs to be generated in the core for conversion to electricity.

Derived By: [104508] Electricity Generation

Linked From: FCS.1

[105335] Fuel Matrix Heat Transfer: The FCS shall be designed to transfer all fuel matrix heat into the primary coolant, with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: Fission heat retained in the fuel matrix has the potential to challenge the fuel temperature design limits and must be prevented to meet MARVEL PDC 10. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104418] PDC.10: Reactor Design, [107753] DOE O 420.1C Attachment 3 Section 3.a.(1), [104508] Electricity Generation

Linked From: FCS.2

[105336] Decay Heat Removal Through Reflectors: The FCS shall facilitate decay heat removal in all operating scenarios, with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: Decay heat will need to be removed following shutdown or scram. The fuel design limits need to be protected in this scenario. This requirement satisfies MARVEL PDCs 34 and 44. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104440] PDC.34: Core Flow/Heat Removal, [107753] DOE O 420.1C Attachment 3 Section 3.a.(1)

Linked From: FCS.3

[105342] Fuel and Core Inherent Reactivity Feedback: The FCS shall be designed to provide sufficient negative reactivity feedback as the temperature of the reactor increases such that it is self-protecting and does not require action from the reactivity control systems to limit reactivity excursions.

Rationale: Inherent reactivity feedback meets the requirements of MARVEL PDCs 11, 12, and 26 to provide a passive method of reactivity control and ensures that the allowable fuel design limits are not exceeded.

Derived By: [104419] PDC.11: Reactor Inherent Protection, [104434] PDC.26: Reactivity Control, [104420] PDC.12: Suppression of Reactor Power Oscillations

Linked From: FCS.4

[105343] Fuel and Core Fission Product Confinement: The FCS shall provide barriers that prevent or mitigate the release of radioactive materials from the reactor to the public and the environment during normal operations, anticipated events, and postulated accident conditions.

Rationale: MARVEL provides radiological confinement to meet PDC 16, and DOE O 420.1C Attachment 2 Chapter I Sections 3.b.(2)(e) and Section 3.b.(3)(a).

Derived By: [104424] PDC.16: Confinement of Radioactive Material, [107739] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(a), [107738] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(e)

Linked From: FCS.5

3.6.2 Level 2 FCS Operational Requirements

[105338] Fuel and Core Design for Operating Environment: The FCS shall be designed to withstand the credited environmental conditions (e.g., temperature, pressure, radiation, etc.) in which it is installed for at least 2 calendar years of operation, with appropriate margin to assure that specified acceptable fuel design limits are not exceeded.

Rationale: SSCs must be rated to withstand their credited condition of operation per MARVEL PDC 4. In particular, the FCS must have sufficient structural integrity to ensure that the specified fuel design limits are not challenged. Margin is added in accordance with DOE O 420.1C Attachment 3 Section 3.a.(1).

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis, [107760] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [107753] DOE O 420.1C Attachment 3 Section 3.a.(1)

[105339] Fuel and Core Seismic Design: FCS SSCs important to safety shall be designed to withstand the effects of seismic events without the loss of the capability to perform their safety functions.

Rationale: A seismic event cannot challenge the ability of the FCS to perform its safety functions per MARVEL PDC 2 and DOE O 420.1C Attachment 2 Chapter IV Section 3.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena, [107752] DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c

[105340] Fuel and Core Excess Reactivity: The FCS shall contain sufficient excess reactivity for at least two calendar years of operation.

Rationale: MARVEL should be designed to operate for at least 2 years. Since the fuel will be sealed inside the vessel, it will not be possible to reload the core.

Derived By: [104510] Design Life

[105341] Material at Risk Minimization: The FCS shall minimize the quantity of material at risk for the project.

Rationale: Minimizing the quantity of material at risk is required as a defense in depth measure per DOE O 420.1C, Attachment 2 Chapter I Section 3.b.(2)(b).

Derived By: [107735] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(b)

[105344] Neutron Source Accommodation: The FCS shall be designed to accommodate a neutron source during reactor startup.

Rationale: The neutron source keeps nuclear startup instruments in range. Startup instrumentation provides indication of reactor power changes at extremely low power levels if the instruments are in their normal response range.

Derived By: [104507] Reactor Startup

[105345] Fuel and Core Decommissioning: FCS components shall be designed to facilitate decommissioning while minimizing radiation dose to personnel to the extent practical (ALARA).

Rationale: The entire lifecycle of the reactor should be considered in the design process. Provisions for D&D are required per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a).

Derived By: [107742] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a)

[105346] Ex-Vessel Subcriticality: The FCS shall be designed to be subcritical during handling operations outside the reactor.

Rationale: The fuel will be assembled into subassemblies outside the reactor and then loaded in the core. Inadvertent criticality must be prevented during installation per MARVEL PDC 62.

Derived By: [104446] PDC.62: Prevention of Criticality in Fuel Storage and Handling

[105347] Structural Support for Fuel and Core Equipment: The FCS shall provide structural support for internal fuel and core SSCs.

Rationale: The fuel and core are supported as an integrated system by the MRS but internal components such as the individual fuel elements and reflectors will need structural support from other FCS components.

Derived By: [104414] PDC.02: Design Bases for Protection Against Natural Phenomena

3.7 Level 2 Requirements - Power Generation System (PGS)

The following diagram shows the primary functions of the PGS, each listed after the diagram. Each function is traceable to the functional requirements in this section. The primary purpose of the PGS is to convert thermal energy to electrical energy for connected end user loads. Any excess heat not needed for the power conversion cycle is rejected to the atmosphere.

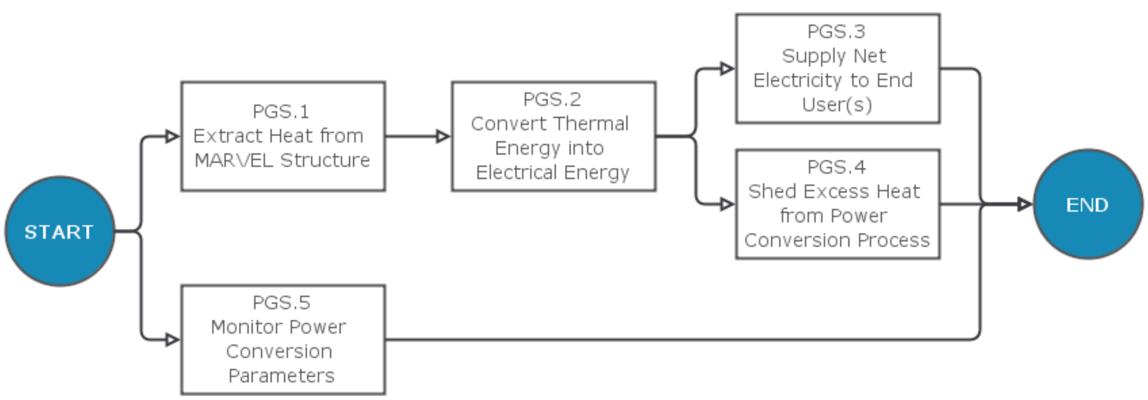

Figure 6 Power Generation System Functional Diagram

PGS.1: Extract Heat from MARVEL Structure

PGS.2: Convert Thermal Energy into Electrical Energy

PGS.3: Supply Net Electricity to End User(s)

PGS.4: Shed Excess Heat from Power Conversion Process

PGS.5: Monitor Power Conversion Parameters

3.7.1 Level 2 PGS Functional Requirements

[105349] Heat Extraction from Reactor: The PGS shall be capable of extracting heat from the MARVEL reactor structure.

Rationale: Heat from the secondary coolant is extracted for downstream power conversion.

Derived By: [104508] Electricity Generation

Linked From: PGS.1

[105350] Electricity Generation: The PGS shall produce electrical power from heat provided by the reactor.

Rationale: MARVEL should be designed for efficient electrical production, minimizing the waste heat fraction.

Derived By: [104508] Electricity Generation

Linked From: PGS.2

[105351] Electrical Supply: The PGS shall be capable of distributing net electrical energy to user loads.

Rationale: The final output of the MARVEL project is net electrical energy that must be supplied to downstream electrical equipment.

Derived By: [104508] Electricity Generation

Linked From: PGS.3

[105352] Excess Power Rejection: The PGS shall reject excess heat or electricity from the power conversion cycle.

Rationale: If electrical power is not consumed by user loads, then the excess power needs to be rejected from the power conversion cycle.

Derived By: [104508] Electricity Generation

Linked From: PGS.4

[113991] Power Conversion Monitoring: The PGS shall monitor power conversion variables and systems over their anticipated ranges for normal operation, for anticipated events, and for postulated accident conditions, as appropriate to ensure adequate safety.

Rationale: This requirement is based on MARVEL PDC 13. Monitoring power conversion parameters also facilitates manual operation in the control room.

Derived By: [104421] PDC.13: Instrumentation and Control

Linked From: PGS.5

3.7.2 Level 2 PGS Operational Requirements

[105353] Power Generation Design for Operating Environment: PGS SSCs within the secondary confinement boundary shall be constructed of materials designed to withstand the credited environmental conditions (e.g., temperature, pressure, radiation, etc.) in which they are installed.

Rationale: Equipment must be designed in consideration of the operating environment per MARVEL PDC 4.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis, [107760] DOE O 420.1C Attachment 3 Section 3.a.(2)(b), [104510] Design Life

[115379] Power Generation System Seismic Design: PGS SSCs shall be designed such that their failure does not prevent safety SSCs from performing their safety functions in a seismic event.

Rationale: The PGS does not perform a seismically qualified safety function but could impact the ability of other safety related SSCs to perform theirs.

Derived By: [107752] DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c, [104414] PDC.02: Design Bases for Protection Against Natural Phenomena

[115351] Power Generation Design for Dynamic Effects: PGS SSCs important to safety shall be appropriately protected against dynamic effects associated with their installed location.

Rationale: Protection from dynamic effects (i.e., events above and beyond environmental conditions such as temperature, pressure, radiation, etc.) is required per MARVEL PDC 4. The PDC clarifies that dynamic effects include things such as missiles, pipe whipping, and discharging fluids that may result from equipment failures.

Derived By: [104416] PDC.04: Environmental and Dynamic Effects Design Basis

[105354] Power Generation Availability: Each PGS train shall provide at least 90% availability during its expected operational life.

Rationale: Power generation equipment is needed for full reactor operation. If this equipment does not demonstrate high availability, then the reactor will constantly be forced to shut down and the project will not be able to fulfill its mission.

Derived By: [104510] Design Life

[105355] PGS Controls: The PGS shall have sufficient controls to interface with other systems for startup, shutdown and power ramping.

Rationale: Interfacing with the ICS is critical for reactor safety an operations.

Derived By: [104508] Electricity Generation

3.7.3 Level 2 PGS Maintenance Requirements

[105356] Power Generation Inspection and Testing: Normally accessible PGS SSCs shall be designed to permit appropriate periodic inspection and testing of important areas and features.

Rationale: Inspection and testing forms part of a reliability, maintainability, and availability program with the objective of maintaining the reactor in a safe state per DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b).

Derived By: [107743] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b)

[105357] Power Generation Maintenance and Replacement: PGS system equipment shall include provisions for maintenance and removal/replacement while minimizing radiation dose to personnel to the extent practical (ALARA).

Rationale: If power generation equipment fails it should be able to be replaced while the reactor is shut down but still hot. Regular maintenance is also expected during the lifetime of the reactor.

Derived By: [107742] DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a), [104510] Design Life

3.8 Supporting Information

3.8.1 Need for Configuration Management

Modifications to MARVEL will be configuration managed in accordance with MFC and TREAT Engineering processes.

3.8.2 Sensitive Information

MARVEL will be access controlled during operations.

3.8.3 Export Control

INL export control processes will be followed when providing information to outside entities.

3.8.4 Need for Engineering Change Control

Engineering change control will follow the Asset Suite Engineering Change (EC) module and its processes, per the INL Conduct of Engineering.

3.8.5 Level of Verification Needed

The minimum level of verification for all requirements of MARVEL will be technical checking, informal design review, and formal design review. Additional rigor will be applied when determined necessary by the Technical Integrator and based on the quality level of the system.

3.8.6 Technical Integrator

The TREAT Engineering Manager is the Technical Integrator for this work.

4. Appendix

Appendix A, Source Documents and References

Appendix B, MARVEL Project Requirements Philosophy

Appendix C, PDC and DOE O 420.1C Mapping Matrix

Appendix A Source Documents and References

DOE/EA-2146, Final Environmental Assessment for the Microreactor Applications Research, Validation, and Evaluation (MARVEL) Project at Idaho National Laboratory, U.S. Department of Energy Idaho Operations Office, 2021

[105375] DOE O 420.1C, Chg 3 (LtdChg), "Facility Safety", U.S. Department of Energy, 2019

[105374] DOE-STD-1066-2016, "Fire Protection", U.S. Department of Energy, 2016

[105373] DOE-STD-1189-2016, "Integration of Safety into the Design Process", U.S. Department of Energy, 2016

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

[105370] IEEE 323-2003 (R2008), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, 2008

[105371] IEEE 379-2014, IEEE Standard for Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems, Institute of Electrical and Electronics Engineers, 2014

[105372] IEEE 627-2019, IEEE Standard for Qualification of Equipment Used in Nuclear Facilities, Institute of Electrical and Electronics Engineers, 2019

MCP-18121, "Safety Analysis Process," Rev. 5, Idaho National Laboratory

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

SDS-119, "Safety Design Strategy for the Microreactor Applications Research Validation and Evaluation (MARVEL) Project," Rev. 0, Idaho National Laboratory

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

TFR-2575, "MARVEL Power Generation System (PGS)," Rev. 0, Idaho National Laboratory

TFR-2576, "MARVEL Reactor Structure (MRS)," Rev. 0, Idaho National Laboratory

TFR-2577, "MARVEL Fuel and Core System (FCS)," Rev. 0, Idaho National Laboratory

TFR-2578, "MARVEL Reactivity Control System (RCS)," Rev. 0, Idaho National Laboratory

Nuclear Energy Innovation and Capabilities Act (NEICA) in September of 2018, Nuclear Energy Innovation Capabilities Act of 2017 (Public Law 115-248 132 Stat 3154), 2018

Appendix B: MARVEL Project Requirements Philosophy

The MARVEL project is organized in a hierarchy of structures, systems, and components (SSCs) based on a systems engineering approach. Similarly, the project requirements are arranged in tiers that directly correspond to the physical asset hierarchy. The figure below shows the overall requirements philosophy for the project.

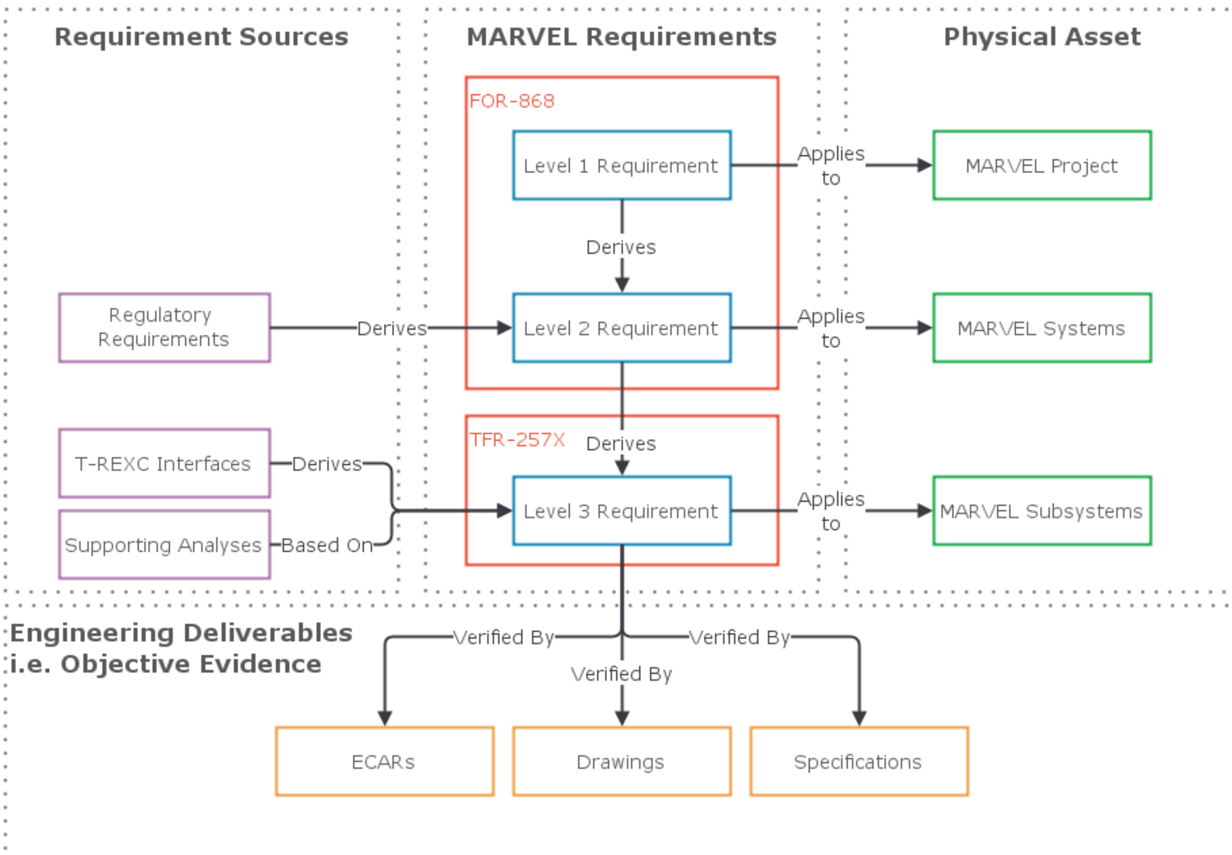

Figure 7 MARVEL Requirements Philosophy

Appendix C: PDC and DOE O 420.1C Mapping Matrix

The matrix exported from the project requirements management database below provides the mapping between the design criteria from the MARVEL PDCs (derived from NRC RG 1.232 and tailored in SAR-420-ADD-1) and DOE Order 420.1C. The "Project Allocation" column determines the responsible project (MARVEL vs. T-REXC) for implementing the regulatory requirement. In some cases, both projects work in conjunction to satisfy the overall requirement (i.e., confinement). In those cases, both projects are listed in the "Project Allocation" column. The matrix then provides the implementing requirements found either in this FOR or FOR-684 governing the design of T-REXC.

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.02: Design Bases for Protection Against Natural Phenomena	Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of all normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.	The requirements for natural phenomenon hazard (NPH) design from DOE O 420.1C and DOE-STD-1020-2016, "Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities," were followed for the design and construction of the MARVEL as applicable and appropriate. Consistent with the requirements of DOE O 420.1C and DOE STD-1020-2016, NPH design criteria were established by performing a conservative estimate of the potential unmitigated consequences as a result of NPH induced failure of MARVEL SSCs. Corresponding NPH criteria were established based upon the potential for the specific NPH to create a postulated accident event and the corresponding consequence of the identified event. Based on the evaluation in ECAR-5127, "Evaluation of the MARVEL Reactor Inhalation Dose Consequences," MARVEL SR and NSR-AR SSCs are categorized using the criteria in DOE-STD-1020-2016 as NPH design category (NDC)-2 and seismic design category (SDC)-2.	MARVEL,T-REXC	105311: Structural Support for Reactivity Control Elements 105319: Structural Support for Reactor 105347: Structural Support for Fuel and Core Equipment 104526: Instrumentation and Control Seismic Design 105339: Fuel and Core Seismic Design 105327: Reactor Structure Seismic Design 105305: Reactivity Control Seismic Design
PDC.03: Fire Protection	Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and fire-resistant materials shall be used wherever practical throughout the unit, particularly in locations with structures, systems, or components important to safety. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to ensure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.	Reliability and survivability of identified SR and NSR-AR SSCs will be considered in the MARVEL design efforts as applicable and appropriate. Consistent with the requirements of DOE-STD-1066, an evaluation of the potential for failure of SR and NSR-AR SSCs will be performed in the fire hazards analysis and appropriate preventive and mitigative measures to ensure survivability will be included into the MARVEL design as applicable and appropriate. MARVEL construction materials were selected for compatibility with NaK to minimize energetic NaK reactions in areas where NaK leaks are present as well as minimizing to the maximum extent practicable, locations where NaK and water may be proximately located. The MARVEL contains appropriate fire detection and suppression systems to identify, detect, alarm, and mitigate both NaK and combustible material fires. Specific evaluation and selection of appropriate NaK fire mitigation strategies were performed based upon the varying physical locations and associated hazards. Fire suppression systems are designed and evaluated in such a manner as to minimize their potential adverse impact on overall safety and reliability. Design solutions have been selected which most effectively ensure the prevention or ability to mitigate potential fire scenarios while ensuring that reactor safety and overall risk is reduced.	MARVEL,T-REXC	105328: Reactor Structure Fire Protection 104784: Instrumentation and Control Fire Protection

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.04: Environmental and Dynamic Effects Design Basis	Structures, systems, and components important to safety shall be designed to accommodate the effects of, and to be compatible with, the environmental conditions associated with normal operation, maintenance, testing, anticipated operational occurrences, and postulated accidents, including the effects of NaK and its aerosols and oxidation products. These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.	Appropriate environmental conditions applicable to MARVEL SSCs designated in Section 3.2 as SR and NSR-AR under all normal operation, maintenance, testing, anticipated event, and postulated accident conditions, were identified in the design process, as well as criteria for evaluation and demonstration of ability of SSCs to perform their safety functions. MARVEL SSC failures and associated impacts on safety systems were considered to ensure that lower classified or other similarly classified systems would not fail in such a way that the ability to perform safety functions are compromised. Pipe whip is not considered a MARVEL concern compared to existing LWRs due to the much lower operating pressure. Environmental conditions due to NaK leakage or approved NaK operating conditions were included and evaluated in the MARVEL preliminary design.	MARVEL,T-REXC	105338: Fuel and Core Design for Operating Environment 104525: Instrumentation and Control Design for Operating Environment 105304: Reactivity Control Design for Operating Environment 105326: Reactor Structure Design for Operating Environment 105353: Power Generation Design for Operating Environment 115350: Reactor Structure Design for Dynamic Effects 115351: Power Generation Design for Dynamic Effects
PDC.05: Sharing of Structures, Systems, and Components	Structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.	MARVEL is a single unit microreactor located in the TREAT facility in the north high-bay equipment pit. Shared SSCs between the TREAT facility and MARVEL were evaluated in the preliminary design to ensure a postulated accident in one reactor will not inhibit the SR and NSR-AR SSC safety functions in the other.	T-REXC	
PDC.10: Reactor Design	The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.	MARVEL SSCs necessary for reactivity control, heat removal, and radioactive material confinement will be designed in conjunction with the results of operational and accidental safety analyses to ensure that fuel design limits are clearly established and that the design is capable of keeping the reactor within the established limits for all normal and accident conditions.	MARVEL	104515: System Control for Normal Operating Conditions 104516: Automatic Reactor Shutdown 105335: Fuel Matrix Heat Transfer 105315: Core Heat Removal
PDC.11: Reactor Inherent Protection	The reactor core and associated systems that contribute to reactivity feedback shall be designed so that, in the power operating range, the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.	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 PCB temperature limits are challenged, or before core damage occurs during anticipated events and postulated accident conditions.	MARVEL	105342: Fuel and Core Inherent Reactivity Feedback
PDC.12: Suppression of Reactor Power Oscillations	The reactor core; associated structures; and associated coolant, control, and protection systems shall be designed to ensure that power oscillations that can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.	The MARVEL reactor core is designed for axial and radial stability. The reactor core and associated coolant, control, and protection systems ensure that power and hydraulic oscillations that can result in conditions exceeding fuel, clad, and PCB temperature limits are not possible.	MARVEL	105300: Reactivity Change Control 105342: Fuel and Core Inherent Reactivity Feedback

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.13: Instrumentation and Control	Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions, as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core, the primary coolant boundary, and the confinement barriers and associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.	MARVEL instrumentation and control (I&C) hardware is designed to monitor variables and systems over the anticipated ranges for normal operation, anticipated events, and postulated accident conditions. A reactor instrumentation and control system is provided to ensure that MARVEL operations and controls are performed in a manner which keeps plant parameters and systems within their prescribed operating ranges. The only instrument that is SR is the pressure indication, which verifies the pressure in the guard vessel and reactor barrel can perform their safety function to prevent the core from being uncovered in the case of a large break of the primary coolant loop . The same I&C hardware used for normal operations is also used for post-accident monitoring. The limitations imposed by the interlocks and software will keep the operations within the prescribed operating ranges, either through inherent physical means or defense in depth measures.	MARVEL	104513: Reactor Parameter Monitoring 104515: System Control for Normal Operating Conditions 113991: Power Conversion Monitoring
PDC.14: Primary Coolant Boundary	The primary coolant boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.	MARVEL PCB SSCs, described in detail in Addendum Chapter 5, Reactor Coolant System, have been designed to ensure that they are capable of withstanding the normal operating conditions, anticipated events, and postulated accident conditions as applicable and appropriate.	MARVEL	105326: Reactor Structure Design for Operating Environment
PDC.15: Primary Coolant System Design	The primary coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the primary coolant boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.	The design of the MARVEL primary coolant system (PCS) system, described in detail in Addendum Chapter 5, Reactor Coolant System, considers appropriate conservatism and factors of safety to ensure that margins are maintained for normal operations, anticipated events, and postulated accident conditions.	MARVEL	104515: System Control for Normal Operating Conditions 105315: Core Heat Removal 104516: Automatic Reactor Shutdown

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.16: Confinement of Radioactive Material	A reactor functional confinement strategy, consisting of multiple barriers internal and/or external to the reactor and its cooling system, shall be provided to control the release of radioactive and hazardous material to the environment, and to ensure that the functional confinement barrier design conditions are not exceeded for as long as postulated accident conditions require.	The MARVEL functional confinement strategy is derived from a performance-based perspective in that the confinement barrier performance requirements are derived from the MARVEL accident analysis and not prescriptively required such as for a typical LWR pressure-retaining containment structure. The evaluated MARVEL design has the following strategies for limiting the release of radionuclides: • Fuel, cladding, and primary coolant (NaK), • PCB including reactor barrel and piping (downcomers), • Guard vessel, and • TREAT microReactor eXperiment Cell (T-REXC) SSCs The FSF of limiting the release of radioactive and hazardous material represents the ultimate objective of protecting the public, collocated worker, and facility worker. The MARVEL design incorporates passive features to address the avoidance of precursor conditions that would challenge or exacerbate the release of radioactive or hazardous materials. The MARVEL fuel retains many radionuclides within its matrix. The cladding around the fuel provides a barrier for gaseous fission products (i.e., xenon, krypton), if damage were to occur. Damage to the fuel cladding releases radionuclides to the primary NaK coolant. The NaK coolant acts as a third radionuclide barrier by retaining fission products by plate-out, chemical solubility, or adsorption mechanisms. The PCB design, which includes the reactor barrel and any associated piping, including the downcomers, ensures primary NaK and any leaked fission or activation products remain within the barrel and oxygen remains outside. The PCB is required to remain intact and may be degraded as a result of increased bulk coolant temperature. The guard vessel provides an additional confinement barrier for the release of primary coolant and prevents the core from being uncovered during a postulated loss of coolant accident (LOCA) by controlling the void space inside the guard vessel. The guard vessel also prevents NaK-air, NaK water, NaK-concrete, and NaK organics interactions. The T-REXC SSCs provide for the removal of decay heat from the TREAT reactor building, and the final DID control of any radioactive or hazardous material effluent during normal operations or in the very unlikely failure of any of the above primary barriers during postulated accidents. The PCB design, which includes the reactor barrel and any associated piping, including the downcomers, ensures primary NaK and any leaked fission or activation products remain within the barrel and oxygen remains outside. The PCB is required to remain intact and may be degraded as a result of increased bulk coolant temperature. The guard vessel provides an additional confinement barrier for the release of primary coolant and prevents the core from being uncovered during a postulated loss of coolant accident (LOCA) by controlling the void space inside the guard vessel. The guard vessel also prevents NaK-air, NaK water, NaK-concrete, and NaK organics interactions. The T-REXC SSCs provide for the removal of decay heat from the TREAT reactor building, and the final DID control of any radioactive or hazardous material effluent during normal operations or in the very unlikely failure of any of the above primary barriers during postulated accidents.	MARVEL,T-REXC	105343: Fuel and Core Fission Product Confinement 105329: Reactor Structure Fission Product Confinement 113979: Reactivity Control Fission Product Confinement

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.17: Electrical Power Systems	Electric power systems shall be provided when required to permit functioning of SSCs. The safety function for each power system shall be to provide sufficient capacity and capability to ensure that (1) that the design limits for the fission product barriers are not exceeded as a result of anticipated operational occurrences and (2) safety functions that rely on electric power are maintained in the event of postulated accidents. The electric power systems shall include an onsite power system and an additional power system. The onsite electric power system shall have enough independence, redundancy, and testability to perform its safety functions, assuming a single failure. An additional power system shall have enough independence and testability to perform its safety function. If electric power is not needed for anticipated operational occurrences or postulated accidents, the design shall demonstrate that power for important to safety functions is provided.	RG 1.232 provides some clarification on this topic by stating, "In this context, important to safety functions refer to the broader, potentially non-safety related functions such as post-accident monitoring, control room habitability, emergency lighting, radiation monitoring, communications and/or any others that may be deemed appropriate for the given design." MARVEL system passive design and construction is such that normal electrical power is provided to all systems where such capability is required for appropriate system functions. Normal power to the TREAT facility is discussed in detail in SAR-420, Chapter 8. Normal power is site commercial power, supplied over a pole line from the Materials and Fuels Complex (MFC)-768 Power Plant 13.8-kV system. Electrical power does not intrinsically perform a FSF in the MARVEL design. MARVEL is designed with passive SR SSCs for safe shutdown, core flow/heat removal, and confinement boundary integrity. Electrical power is not relied upon to meet design limits for the fission product barriers as a result of anticipated events or postulated accidents. The availability of electrical power sources does not affect the ability to achieve and maintain SR functions. NSR-AR electrical system SSCs have been identified in Addendum Chapter 15 to provide power to NSR-AR instruments and monitoring panels for monitoring safe plant shutdown from the control room and for post-accident monitoring.	T-REXC	
PDC.18: Inspection and Testing of Electric Power Systems	Electric power systems important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems shall be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among systems.	There are no SR electric power SSCs identified in the Addendum Chapter 15 Accident Analyses, required to meet this PDC. NSR-AR SSCs have been evaluated for meeting this Criterion as discussed in greater detail in Addendum Chapter 8, Electric Power Systems.	T-REXC	

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.19: Control Room	A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem TEDE, as defined in § 50.2 for the duration of the accident. Adequate habitability measures shall be provided to permit access and occupancy of the control room during normal operations and under accident conditions. Adequate protection against sodium aerosols shall be provided to permit access and occupancy of the control room under accident conditions. Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.	The MARVEL control room will be collocated with the TREAT control room. There are no MARVEL credited SR operator actions under postulated accident conditions. Shutdown and monitoring functions of the control room are not required by the accident analyses in Addendum Chapter 15 for accident mitigation. The accident analyses in Addendum Chapter 15, identifies that manual scram by the control room operator may be required for long term shutdown of the reactor under postulated accident conditions, and manual scram SSCs are therefore SR. The control room has a manual scram button to allow the operator to cut the power to the electromagnets and scram the reactor. This action can achieve cold shutdown, which bounds the hot shutdown. Radiological and non-radiological consequences to workers are limited by the distance from the TREAT building to the TREAT control room, and by evacuation of the TREAT building during transient and MARVEL operations. Radiological and non-radiological consequences to workers are well within the evaluation guidelines in Addendum Chapter 15 at the control room and no measures are required for ensuring habitability	T-REXC	
PDC.20: Protection System Functions	The protection system shall be designed (1) to initiate automatically the operation of appropriate systems including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of systems and components important to safety.	MARVEL is provided with a reactor protection system (RPS) to ensure reactor shutdown under anticipated events and postulated accident conditions. Design and performance requirements for the RPS have been developed to meet the requirements for safety systems from associated standards based upon the safety functions identified in the hazard and accident analysis. The use of standards cited by and referenced in DOE O-420.1C are used on a graded basis, based on the function of the SSC and importance in the accident analysis. Addendum Chapter 15 takes no credit for all automatic systems and sensing of accidents, with the exception of the seismic sensor. The seismic sensor is SR and is an input to the RPS. When the P-wave reaches the seismic sensor, it will release a relay which will release the electromagnets and shutdown the reactor. There are several automatic and accident sensing trips that serve as defense-in-depth (DID) and are called computer trips.	MARVEL	105311: Structural Support for Reactivity Control Elements 104518: Postulated Accident Scram 104516: Automatic Reactor Shutdown

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.21: Protection System Reliability and Testability	The protection system shall be designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to assure that (1) no single failure results in loss of the protection function and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.	Consistent with the requirements of DOE O 420.1C and supporting standards, MARVEL RPS SR, and NSR-AR SSCs, as identified in the hazard and accident analysis, include features for high reliability by including requirements and criteria for redundancy and independence. Provisions for ensuring the ability to monitor the status of the RPS and perform appropriate surveillance tests and monitoring functions to assure RPS functionality are incorporated into the plant design and operating philosophy as applicable and appropriate. There are certain aspects of PDC-21 that are not applicable. The MARVEL system is not designed to have any in-service testing or testing with the reactor in operation. The RPS can be tested independently. Removal of any component from the RPS will automatically cause the RPS to perform its safety function because the electromagnets will not be able to be powered. The RPS has been designed with single failure built into the design by analysis and adding redundant and independent features. No single failure in the RPS will result in a loss of the protection function. The MARVEL RPS complies with the single failure criterion. There are no provisions for taking a channel out of service with the reactor operating. No in-service testing or maintenance is planned. The RPS will fail into a safe state upon loss of power or disconnection. The RPS SSCs are designed so that the loss of power will automatically result in a shutdown of the reactor. Commercial power reactors need detailed reliability analysis to demonstrate that the protection systems can reliably mitigate the accidents described in the accident analyses. The RPS for MARVEL is not required to mitigate any accidents described in Addendum Chapter 15. The reliability of the MARVEL RPS is achieved by use of IEEE-379, IEEE Standard for Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems. The MARVEL RPS does not need a formal, detailed reliability analysis, so IEEE-352 is not applicable. This SFR-DC was written for commercial power stations that are expected to operate for long periods of time without shutdown. MARVEL is planned to operate only for a few days at a time, and to be regularly shutdown. This criterion explicitly allows for exception to testing and calibration during power operation are allowed where this capability cannot be provided without adversely affecting the safety or operability. The MARVEL safety related I&C system can be testing and calibrated when MARVEL is shutdown and maintain sufficient reliability.	MARVEL	104785: Instrumentation and Control Inspection and Testing 105312: Reactivity Control Inspection and Testing 104780: Instrumentation and Control Single Failure Criterion 105307: Reactivity Control Single Failure Criterion
PDC.22: Protection System Independence	The protection system shall be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.	Consistent with PDC-22, MARVEL RPS SR and NSR-AR SSCs identified in the Addendum Chapter 15 hazard and accident analysis are subject to the appropriate requirements for NPH qualification. No RPS SSCs have been identified in Addendum Chapter 15 that are subject to PDC-22 requirements for functional and component diversity. This is because all the postulated accidents rely on passive means to mitigate the accident until a manual shutdown can be performed by an operator to result in a cold shutdown.	MARVEL	104526: Instrumentation and Control Seismic Design 104780: Instrumentation and Control Single Failure Criterion 105307: Reactivity Control Single Failure Criterion 105305: Reactivity Control Seismic Design

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.23: Protection System Failure Modes	The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis, if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, NaK and NaK reaction products, pressure, steam, water, and radiation) are experienced.	MARVEL RPS SR and NSR-AR SSCs, identified in the hazard and accident analysis, are subject to the appropriate requirements for either safe failure mechanisms. The RPS is designed to fail with the result being a reactor shutdown. Likewise, the reactivity control system (RCS) is designed to result in a safe state with loss of energy.	MARVEL	104527: Instrumentation and Control Fail Safe State 105306: Reactivity Control Fail Safe State
PDC.24: Separation of Protection and Control Systems	The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to assure that safety is not significantly impaired.	MARVEL RPS SR and NSR-AR SSCs, identified in the hazard and accident analysis, are subject to the appropriate requirements for redundancy and diversity in sensors as well as the manner in which they are connected precludes the ability for a single failure within either system from adversely affecting the performance of the other system. MARVEL RPS SR and NSR-AR SSCs, identified in the Addendum Chapter 15 hazard and accident analysis, are subject to the appropriate requirements for interconnection such that failure of lower safety classified systems cannot have an adverse impact on the ability of the RPS to perform its designated safety functions. The RPS will be separated from the control system to the extent that failure of any single component or channel, or failure or removal from service of any single RPS component or channel which is common to the control system or RPS leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. The forcing mechanisms to control the control drums (CDs) and central insurance absorber rod (CIA) rod are independent from the RPS system which releases the electromagnetic clutch and separates the control systems from the protection systems. This clutch defaults to the disconnection with no power. No postulated failure has been found to challenge the ability of the SSCs from performing their safety functions.	MARVEL	104781: Independence from Control System
PDC.25: Protection System Requirements for Reactivity Control Malfunctions	The protection system shall be designed to ensure that specified acceptable fuel design limits are not exceeded during any anticipated operational occurrence accounting for a single malfunction of the reactivity control systems.	MARVEL RPS SR and NSR-AR SSCs, identified in the hazard and accident analysis, are subject to the appropriate requirements to ensure that any single malfunction will not impair the ability of the system to perform its associated safety function, which will result in ensuring that no design limits for the fission product barriers are challenged. The design of the interlock relays, the hard stops and the procedural requirements on only one CD above the critical banked position were designed for the purpose of restricting a single malfunction of the reactivity control system. The interlock relays force only one CD to be moved at once. The procedures limit only one CD to be moved beyond critical so that the reactivity between critical and the hard stop are the total excess reactivity that can be achieved with a malfunction. The hard stop restricts the reactivity to a level below the transient overpower (TOP) transient limit in Addendum Chapter 15. Additionally, there are DID measures from the control computer to enforce operations and reactivity limits with automatic shutdowns if those limits are exceeded.	MARVEL	105307: Reactivity Control Single Failure Criterion 104780: Instrumentation and Control Single Failure Criterion

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.26: Reactivity Control	A minimum of two independent reactivity control systems or means of different design principles shall be provided. 1) One of the means shall be capable of reliably controlling reactivity changes to ensure that under conditions of normal operation, including anticipated events, and with appropriate margin for malfunctions, design limits for the fission product barriers are not exceeded. 2) The second means shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes to ensure design limits for the fission product barriers are not exceeded. 3) One of the means shall be capable of holding the reactor core subcritical under cold conditions. 4) The means shall be designed to have a combined capability to ensure that under postulated accident conditions, excess reactivity does not cause the design limits for the fission product barriers to be exceeded and that the reactor core is subcritical with appropriate margin.	The importance of reactivity control is that it is the means to control the generation of heat in the reactor. Imbalances between the heat generation and the heat removal in the reactor core lead to changes in core temperatures. The FSF of controlling reactivity is intended to control normal plant operation and to prevent abnormal plant conditions from escalating into a more significant accident. Reactivity control also helps facilitate any response to a postulated accident, should one occur, by shutting down the nuclear reaction and reducing the heat generation within the plant that other installed systems (e.g., CDs) would be required to mitigate. The evaluated MARVEL micro-reactor design has the following strategies for reactivity control: • IRF • CDs • CIA rod The first and primary means of limiting fuel temperature during postulated accident conditions is by the control of the reactivity of the reactor through the passive insertion of negative reactivity. IRF is not a physical SSC but relies on core system SSCs to provide system performance related to geometric and physics changes in order to provide 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 PCB temperature limits are challenged and core damage occurs. The CDs release following a signal from the RPS to provide insertion of negative reactivity to shutdown the reactor and maintain in shutdown condition. The reactor trip system monitors reactor process variables and sends a reactor trip signal when a process variable exceeds a limit setpoint. The CD system is designed to limit both the rate and magnitude of reactivity insertion that the system can achieve so as to minimize the effect of an unintended reactivity insertion. The CD system consists of four independent mechanical assemblies evenly spaced within the radial neutron reflector around Marvel's core. A single CD can bring the reactor subcritical in a hot operation condition. This provides excellent redundant shutdown capability as there are four independently controlled CDs. The CIA rod provides DID reactor shutdown capability in the beyond design basis scenario that common mode failure prohibits insertion of more than one CD. The CIA rod alone can bring the reactor subcritical in all credible accident scenarios at a hot operation condition. The CIA rod plus one CD allows for shutdown of the reactor in all conditions. Finally, the MARVEL reactivity control strategy is implemented in the FSFs discussed in detail in Addendum Chapter 6, Engineered Safety Features, to keep IEs from progressing to end states that could result in core damage and release of radioactive material.	MARVEL	105302: Negative Reactivity 105342: Fuel and Core Inherent Reactivity Feedback 105300: Reactivity Change Control
PDC.28: Reactivity Limits	The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither (1) result in damage to the primary coolant boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor vessel internals to impair significantly the capability to cool the core.	The following design and administrative controls limit reactivity: 1) The interlock relays limit movement to 1 CD at a time (design control), 2) The hard stop limits the max reactivity of a CD (design control), 3) The operations must only move one CD above critical (administrative control), and 4) The gray rod limits total excess down to give margin for errors in calculations (design control). The design of the RCS CD and CIA rod SSCs is discussed in further detail in Addendum Chapter 4, Reactor.	MARVEL	104521: Reactor Power Level Control 105300: Reactivity Change Control

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.29: Protection Against Anticipated Operational Occurrences	The protection and reactivity control systems shall be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.	MARVEL RPS and reactivity control system SR and NSR-AR SSCs, identified in the hazard and accident analysis, are high reliability systems which are designed to minimize plant upset conditions and ensure performance of safety functions during anticipated events and postulated accident conditions. The anticipated events are listed in Addendum Chapter 15. Each of the initiating events are presented below along with how PDC-29 was considered for that phenomena and that apply to this system. Shutdowns: The operational occurrences presented include manual shutdown, test scrams and spurious trips. The manual shutdowns and test scrams are inherent functions of the RPS system and require no extra consideration. The spurious trips are limited by applying standard wiring techniques to limit noise sources that cause spurious trips. General Transients: The operations occurrences include small reactivity changes and small coolant NaK leaks. The small reactivity changes include things like miss-positioning of a single CD or flux tilt to increase the temperature in an assembly. The I&C system will be used as a tool to inform operators of the reactivity, power, and temperature so that they can make informed decisions with regard to small reactivity changes. There are also NaK detectors that can pickup a cumulative loss of 3 cubic inches or less. This is accomplished by designing the guard vessel to slope down at all points and a cup of 2.54 cubic inches at the very bottom of the vessel where the leak detectors reside. Decrease in Heat Removal by Secondary System: This includes the loss of power in the Stirling engines and small pipe leaks. The small pipe leaks are similar to the small coolant NaK leaks since the only pipes are located within the guard vessel. The loss of power in the Stirling engines is expected to be indicated by a warning or error from the engine controller. Depending on the severity, the system will automatically be scrammed, or the operators will be warned of the event and may perform a manual scram. Loss of power (LOP): This RPS was designed to automatically scram if a loss of power event occurs. The engine I&C system is able to be maintained with long term diesel generator backup and other systems have short term battery backup to provide enough time for the operators to verify the system has been shutdown. Power Distribution Anomalies: The anticipated event related to I&C is the overcooling of the primary system by the power conversion unit. At the present time the operators will maintain full control over the power conversion unit. It is anticipated that once the as built system is well characterized more control function can be added to perform automatic operation over the power conversion unit. Radioactive or Hazardous Material Release, or Direct Radiation Exposure: The anticipated events include radioactive or hazardous releases or exposures. The facility will have radiation monitoring equipment to inform personnel of the radiation levels and any other potential hazard that can be detected. Facility Fires: The anticipated event is a NaK spill or fire. The facility monitoring will have a smoke detector and is provided by the facility. The facility will handle other monitoring related to the NaK filling. A firewall will also be in place.	MARVEL	104780: Instrumentation and Control Single Failure Criterion 104781: Independence from Control System

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.30: Quality of Primary Coolant Boundary	Components that are part of the primary coolant boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of primary coolant leakage.	The MARVEL PCB has appropriate design and procurement requirements which are verified by adherence to the MARVEL quality assurance program. The potential for leakage from the PCB within the MARVEL is extremely limited, however the need for provisions for detecting the leakage and to the extent practicable the location of the leakage was evaluated in the preliminary design. I&C instrumentation includes NaK leak detectors that are provided to 1) signal triggered when in contact with NaK, 2) detect a NaK leak into the guard vessel, and 3) detect if the NaK that has leaked into the guard vessel has reduced the NaK inventory in the primary to uncover the core. The pressure difference between the guard vessel and the reactor barrel is monitored to keep the core from being uncovered in a LOCA event. A discrepancy in the guard vessel pressure indicates a leak in the guard vessel, a leak in the reactor barrel or a faulty pressure sensor. If there is a leak and the pressures change drastically, the operator will be expected to press the manual scram button. The pressure sensors are qualified to NQA-1 standards as safety related or through commercial grade dedication to ensure fabrication and testing meet high quality standards.	MARVEL	104514: Primary Coolant Leak Detection
PDC.31: Fracture Prevention of Primary Coolant Boundary	The primary coolant boundary shall be designed with sufficient margin to ensure that, when stressed under operating, maintenance, testing, and postulated accident conditions, (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures, service degradation of material properties, creep, fatigue, stress rupture, and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation and coolant composition, including contaminants and reaction products, on material properties, (3) residual, steady–state, and transient stresses, and (4) size of flaws.	The performance of the MARVEL PCB under stressed condition is ensured by selection of materials which behave in a ductile manner over the range of MARVEL operating temperatures. The MARVEL PCB design material selection is focused on ensuring that the selected materials can perform their identified design functions under all anticipated events and postulated accident conditions and are subject to the appropriate environmental qualification requirements. The PCB is a metal weldment made from 316H stainless steel for high temperature reactors designed in accordance with ASME Section III Division 5. Finite element analysis (FEA) of the PCB has confirmed the design limits of ASME BPVC Section III Division 5 paragraph HBB-3222.1 have not been exceeded; and (2) load-controlled stress limits and strain and deformation limits for Level A, B, C, and D Service Loadings per paragraphs HBB-3223, HBB-3224, HBB-3225, and Nonmandatory Appendix HBB-T will be managed by the operating conditions of the reactor. The FEA analysis conservatively envelopes the unprotected transient overpower (UTOP) conditions for primary stress in the design limit due to the low operating pressure of the reactor. In addition, the FEA analysis accounts for secondary stresses along with the combined primary membrane plus bending stress intensity to show that the design limits of paragraph HBB-3222.1 have not been exceeded. PCB 316H is expected to have essentially an unlimited lifetime in NaK (no corrosion), given the anticipated purity of the given NaK at 1 ppm oxygen level (Vol V Sodium and NaK Handbook). At present it is planned to control the oxygen content in NaK through (i) a barrel vacuum-purge prior to NaK fill and (ii) use of argon cover gas after NaK fill.	MARVEL	105326: Reactor Structure Design for Operating Environment
PDC.32: Inspection of Primary Coolant Boundary	Components that are part of the primary coolant boundary shall be designed to permit (1) periodic inspection and functional testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor vessel.	A combination of boundary monitoring, inspections and functional testing will be performed to ensure adequate performance of the MARVEL PCB as described in Addendum Chapter 5, Reactor Coolant System.	MARVEL	104513: Reactor Parameter Monitoring

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.34: Core Flow/Heat Removal	SSCs responsible for core flow/heat removal shall passively transfer fission product decay heat and other residual heat from the reactor core at a rate such that fuel and vessel temperature limits and the design conditions of the PCB are not exceeded, and safe shutdown is achieved and maintained during normal operation, anticipated events, and postulated accident conditions.	The evaluated MARVEL micro-reactor design has two strategies for heat removal: • Natural circulation and active heat removal via the Stirling engines during normal operations and shutdown • Passive conduction through barrel and CDs and natural draft heat removal from the outside surface of the guard vessel to the surrounding ambient air environment. The FSF of removing heat serves two critical objectives: 1) removal of the generated heat during all normal operations and shutdown conditions and postulated accident conditions to assure that equipment would operate within the environmental envelope for which it is designed and qualified, and 2) to prevent a postulated accident from progressing into a more severe event category and, as such, would serve to mitigate the potential for releases of radioactivity from the facility. Core flow SSCs provide structural, mechanical, and geographic spacing to ensure natural circulation through the fuel assemblies at reactor operating and elevated transient temperatures and ensure passive conduction heat transfer to the passive ambient air heat rejection system is possible. Finally, the MARVEL core flow/heat removal strategy is implemented in the FSFs as discussed in detail in Addendum Chapter 6, to keep IEs from progressing to end states that could result in core damage and release of radioactive material.	MARVEL,T-REXC	105303: Decay Heat Removal Through Reactivity Control Elements 105317: Decay Heat to Ultimate Heat Sink 105336: Decay Heat Removal Through Reflectors
PDC.44: Structural and Equipment Cooling	A system to transfer heat from structures, systems, and components important to safety to an ultimate heat sink shall be provided, as necessary, to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions. Suitable redundancy in components and features and suitable interconnections, leak detection, and isolation capabilities shall be provided to ensure that the system safety function can be accomplished, assuming a single failure.	The passive heat removal system safety function is to maintain heat rejection geometry and features and natural circulation ability during all normal operations and shutdown conditions and anticipated events and postulated accident conditions. Passive heat removal system adequacy is document in the thermal-hydraulic analyses in Addendum Chapter 15, and redundancy, assuming a single failure, is not required.	MARVEL,T-REXC	105315: Core Heat Removal 105317: Decay Heat to Ultimate Heat Sink
PDC.45: Inspection of Structural and Equipment Cooling Systems	The structural and equipment cooling systems shall be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to ensure the integrity and capability of the systems.	The MARVEL system is not designed to have any in-service testing or testing with the reactor in operation.	MARVEL,T-REXC	105331: Reactor Structure Inspection and Testing
PDC.46: Testing of Structural and Equipment Cooling Systems	The structural and equipment cooling systems shall be designed to permit appropriate periodic functional testing to ensure (1) the structural and leaktight integrity of their components, (2) the operability and performance of the system components, and (3) the operability of the systems as a whole and, under conditions as close to design as practical, the performance of the full operational sequences that bring the systems into operation for reactor shutdown and postulated accidents, including the operation of associated systems.	The MARVEL system is not designed to have any in-service testing or testing with the reactor in operation.	MARVEL,T-REXC	105331: Reactor Structure Inspection and Testing

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.60: Control of Releases of Radioactive Materials to the Environment	The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated events. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.	MARVEL systems have been designed to ensure appropriate protection to public and the workers with provisions to suitably control the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated events. Implementation of this PDC is discussed in further detail in Addendum Chapter 11, Radioactive Waste management. The MARVEL reactor is a NaK cooled reactor. During routine operations of MARVEL, the NaK will become activated through neutron interactions. The NaK may also become contaminated with fission products and fissile material if there is a fuel rod leak or failure. Emissions from NaK system leaks are not postulated during normal operations. The MARVEL reactor has an inert cover gas in the reactor barrel to prevent NaK oxidation. The cover gas will activate through neutron interactions and potentially contain fission products and small amounts may leak out of the barrel. The air in the pit will also be activated through neutron interactions. All of the gaseous radioactive waste produced by the MARVEL reactor will be removed from the TREAT building though T-REXC SSCs with any effluent discharged to the environment. A radiation detection system will monitor the radioactivity of the gas exhausted from the MARVEL reactor area ventilation system. Consistent with the MARVEL Environment Assessment,12 radioactive material releases from MARVEL effluent releases are anticipated to be small. As such, MARVEL does not need to hold up gaseous effluents.	MARVEL,T-REXC	105324: Liquid Waste Management 105321: Gaseous Waste Management
PDC.61: Fuel Storage and Handling and Radioactivity Control	The fuel storage and handling, radioactive waste, and other systems that may contain radioactivity shall be designed to ensure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate confinement and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage cooling under accident conditions.	MARVEL fuel handling systems will be designed to ensure appropriate protection to public and the workers with provisions to ensure criticality safety, adequate radiation shielding and retention of radioactive materials within approved confinement boundaries, and to perform these functions under normal and postulated accident conditions. MARVEL fuel handling systems will include provisions in the design for providing assurance of the ability of these systems to perform their functions through appropriate inspections and tests. MARVEL fuel handling systems will be designed to ensure that appropriate radiation protection exists to ensure that the requirements of 10 CFR 835 Subpart K are satisfied. MARVEL fuel handling systems will be designed in such a fashion that it complies with appropriate requirements from various sources associated with ensuring appropriate radiological material confinement under both normal and postulated accident conditions to comply with radiation protection standards, environmental monitoring and permitting standards and nuclear safety accident requirements. MARVEL fuel handling systems will include passive decay heat removal capabilities to ensure reliability under normal operating and upset conditions. There is no fresh or irradiated fuel storage planned for MARVEL outside of the reactor barrel.	MARVEL,T-REXC	105331: Reactor Structure Inspection and Testing

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.62: Prevention of Criticality in Fuel Storage and Handling	Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.	The requirements of DOE O 420.1C and associated American Nuclear Society consensus standards will be complied with in ensuring that fissionable material handling processes ensure prevention of inadvertent criticality. Prevention of inadvertent criticality outside of the reactor is discussed in Addendum Section 9.4. MARVEL fuel elements will be stored at the TREAT facility in shipping/storage packages with assigned CSI values. There will be a cumulative criticality safety index (CSI) limit of 50 for the TREAT facility. The handling of MARVEL fuel elements will include removal from shipping/storage packages, configured into sub-assemblies, and loading of sub-assemblies into the reactor. The criticality analysis, Criticality Safety Evaluation for the MARVEL Reactor Fuel Storage and Handling,13 does not include reactor loading operations. When dry, it would require more than 50 MARVEL fuel elements to go critical. This is substantially more fuel elements that what will be shipped to INL. Therefore, in the absence of moderation there are no credible criticality accident scenarios with MARVEL fuel elements. When arranged in an optimally moderated array, 18 MARVEL fuel elements can achieve criticality. Handling in the TREAT facility will be limited 8 MARVEL fuel elements at one time.	MARVEL,T-REXC	105346: Ex-Vessel Subcriticality
PDC.63: Monitoring Fuel and Waste Storage	Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.	There is no fuel storage planned for MARVEL outside of the reactor barrel.	T-REXC	
PDC.64: Monitoring Radioactivity Releases	Means shall be provided for monitoring the reactor containment atmosphere, spaces containing components for primary system NaK and cover gas cleanup and processing, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated events, and from postulated accidents.	Radiation monitoring of effluent paths and radiation containing atmospheres will be provided to ensure the ability to detect and respond to the potential for release of radioactive materials. However, as discussed in PDC-16, the MARVEL does not have a reactor containment structure meeting the atmosphere monitoring requirements in this SFR-DC.	T-REXC	
PDC.70: Intermediate Coolant System	If an intermediate cooling system is provided, then the intermediate coolant system shall be designed with sufficient margin to assure that (1) the design conditions of the intermediate coolant boundary are not exceeded during normal operations, including anticipated occupational occurrences, and (2) the integrity of the primary coolant boundary is maintained during postulated accidents.		MARVEL	105326: Reactor Structure Design for Operating Environment
PDC.71: Primary Coolant and Cover Gas Purity Control	Systems shall be provided as necessary to maintain the purity of primary coolant NaK and cover gas within specified design limits. These limits shall be based on consideration of (1) chemical attack, (2) fouling and plugging of passages, and (3) radionuclide concentrations, and (4) air or moisture ingress as a result of a leak of cover gas.		MARVEL	105322: Primary Coolant Supply 105320: Cover Gas Supply

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.73: NaK Leakage Detection and Reaction Prevention and Mitigation	Means to detect and identify NaK leakage as practical and to limit and control the extent of NaK-air and NaK-concrete reactions and to mitigate the effects of fires resulting from these NaK-air and NaK-concrete reactions shall be provided to ensure that the safety functions of structures, systems, and components important to safety are maintained. Systems from which NaK leakage constitutes a significant safety hazard shall include measures for protection, such as inerted enclosures or guard vessels.	The guard vessel serves as the secondary confinement boundary for the primary coolant and contains the PCS. The pressure difference between the guard vessel and the reactor barrel is the SR SSC required to keep the core from being uncovered in a LOCA event. If there is a leak and the pressures change drastically, the operator will be expected to press the manual scram button. The postulated reason for this requirement is if there is a leak in reactor barrel or guard vessel, but a LOCA has not occurred. This is possible if the guard vessel leaks or there is a small leak in the reactor barrel in the off-gas region. Operations must shutdown the reactor since the pressure will no longer be able to perform its function. Leak detectors are provided to detect NaK within the guard vessel. Several probes located in a cup at the bottom of the guard vessel so that multiple sensors should be flagged as well the NaK should be directed to that catch basin to minimize the required NaK to generate a signal.	MARVEL	105320: Cover Gas Supply 104514: Primary Coolant Leak Detection 105323: Primary Coolant Leak Collection
PDC.74: NaK/Water Reaction Prevention/Mitigation	Structures, systems, and components containing NaK shall be designed and located to avoid contact between NaK and water and to limit the adverse effects of chemical reactions between NaK and water on the capability of any structure, system, or component to perform any of its intended safety functions.	The guard vessel serves as the secondary confinement boundary for the primary coolant and contains the primary coolant system. If the NaK leak detectors indicate that there is a leak, then a leak must have developed between the guard vessel and the reactor barrel. The guard vessel is analyzed and fabricated per ASME Section 3 Division 5, class B vessel code. In the event of a LOCA the guard vessel prevents the core from being uncovered by providing a controlled, inert environment for the coolant to flow into, as well as preventing adverse reactions between pit SSCs (concrete) or air and maintaining the PCS passive decay heat removal capability.	MARVEL	105320: Cover Gas Supply 105323: Primary Coolant Leak Collection
PDC.75: Quality of the Intermediate Coolant Boundary	Components that are part of the intermediate coolant boundary shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.		MARVEL	105326: Reactor Structure Design for Operating Environment
PDC.76: Fracture Prevention of the Intermediate Coolant Boundary	The intermediate coolant boundary shall be designed with enough margin to ensure that, when stressed under operating, maintenance, testing, and postulated accident conditions, (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized.	Consistent with the PCB, the performance of the MARVEL SCS under stressed condition is ensured by selection of materials which behave in a ductile manner over the range of MARVEL operating temperatures. Additionally, design margins for the SCS are such that the boundary is capable of withstanding normal operations and postulated accident conditions in order to ensure that the safety function of keeping the SCS intact is preserved. The SCS is described in detail in Addendum Chapter 5, Reactor Coolant System.	MARVEL	105326: Reactor Structure Design for Operating Environment
PDC.77: Inspection of the Intermediate Coolant Boundary	Components that are part of the intermediate coolant boundary shall be designed to permit (1) periodic inspection and functional testing of important areas and features to assess their structural and leak tight integrity commensurate with the system's importance to safety, and (2) an appropriate material surveillance program for the intermediate coolant boundary.	The SCS components are designed for at least 2 years of operation without maintenance. SCS components will be inaccessible throughout the operating life of the reactor.	MARVEL	104513: Reactor Parameter Monitoring 105326: Reactor Structure Design for Operating Environment

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
PDC.78: Primary Coolant System Interfaces	When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically incompatible with the primary coolant, the interface location shall be designed to ensure that the primary coolant is separated from the chemically incompatible fluid by two redundant, passive barriers. When the primary coolant system interfaces with a structure, system, or component containing fluid that is chemically compatible with the primary coolant, then the interface location may be a single passive barrier provided that the following conditions are met: (1) postulated leakage at the interface location does not result in failure of the intended safety functions of structures, systems or components important to safety or result in exceeding the fuel design limits, (2) the fluid contained in the structure, system, or component is maintained at a higher pressure than the primary coolant during normal operation, anticipated operational occurrences, shutdown, and accident conditions.	As discussed in PDC-70, the SCS is filled with an inert argon blanket gas to prevent reaction of any NaK which might leak from the PCS. The guard vessel provides a passive barrier completely separating the primary coolant boundary from the TREAT pit and atmosphere.	MARVEL	105323: Primary Coolant Leak Collection 105320: Cover Gas Supply
PDC.79: Cover Gas Inventory Maintenance	A system to maintain cover gas inventory shall be provided as necessary to ensure that the primary coolant NaK design limits are not exceeded as a result of cover gas loss due to leakage from the primary coolant boundary and rupture of small piping or other small components that are part of the primary coolant boundary.	Argon storage is required for initial filling and for cover gas loss during the lifespan of the MARVEL reactor. The inert cover gas system is capable of storing 2500 L of argon and provides the method to fill the primary coolant system and secondary confinement structure with argon cover gas.	MARVEL	105320: Cover Gas Supply
DOE O 420.1C Attachment 0 Section 6	The following DOE technical standards and industry standards are invoked as required methods in this Order in accordance with the applicability and conditions described within this Order. Any technical standard or industry standard that is mentioned in or referenced by this Order, but is not included in the list below, is not invoked by this Order. Note: DOE O 251.1D, Appendix J provides a definition for "invoked technical standard." 1. a. DOE Standard (STD)-3009-2014, Preparation of Nonreactor Nuclear Facility Documented Safety Analysis. This DOE technical standard is required to be used for specified new non-reactor hazard category 1, 2, and 3 nuclear facilities and major modifications to hazard category 1, 2, and 3 non-reactor nuclear facilities. In addition, Section 3.3.1 of this technical standard is required to be used for existing DOE nuclear facilities that have mitigated off-site dose estimates greater than 25 rem. See Section 4 and Attachment 1 for specific requirements. 2. b. DOE-STD-1104-2016, Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents. This DOE technical standard is	See the MARVEL Code of Record for the inclusion of the required codes and standards. The MARVEL Safety Design Strategy specifies the use of NRC RG 1.70 for formatting the DSA in lieu of DOE STD 3009-2014. Similarly, NUREG-0800 is specified for review of the DSA in lieu of DOE STD 1104-2016.	MARVEL,T-REXC	

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
	required to be used by DOE personnel for review and approval of safety basis and safety design basis documents. See Section 4 for specific requirements. 3. c. DOE-STD-1189-2016, Integration of Safety into the Design Process. This DOE technical standard is required to be used for development and integration of safety analysis and supporting design for new hazard category 1, 2, and 3 nuclear facilities and major modifications to existing hazard category 1, 2 and 3 nuclear facilities. See Attachment 2, Chapter I for specific requirements. 4. d. DOE-STD-3007-2017, Preparing Criticality Safety Evaluations at DOE Nonreactor Nuclear Facilities. This DOE technical standard is required to be used for conduct of criticality safety evaluations at DOE facilities and activities with the potential for inadvertent criticalities, unless another documented method is approved by DOE. See Attachment 2, Chapter III for specific requirements. 5. e. DOE-STD-1020-2016, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities. This DOE technical standard is required to be used for developing the design of new facilities and major modifications. See Attachment 2, Chapter IV for specific requirements. 6. f. American National Standards Institute (ANSI)/American Nuclear Society (ANS)-8 Nuclear Criticality Safety Standards. This set of industry standards is required to be satisfied by Criticality Safety Programs for facilities and activities with the potential for inadvertent criticalities, unless otherwise modified and approved by DOE. See Attachment 2, Chapter III for specific requirements. 7. g. Institute of Electrical and Electronics Engineers (IEEE) 379-2014, IEEE Standard for Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems. This industry standard is required to be applied to the design of safety-class structures, systems, and components (SSCs) for new nuclear facilities and major modifications, unless another applicable standard is approved by DOE. See Attachment 3 for specific requirements. 8. h. IEEE 323-2003 (R2008), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations. This industry standard is required to be used to ensure environmental qualifications of safety-class SSCs for new nuclear facilities and major modifications, unless another applicable standard is approved by DOE. See Attachment 3 for specific requirements.			

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
	9. i. IEEE 384-2008, IEEE Standard Criteria for Independence of Class IE Equipment and Circuits. This industry standard is required to be used for new nuclear facilities and major modifications for physical and electrical separation methods, including the use of separation distance, barriers, electrical isolation devices, or any combination thereof, unless another applicable standard is approved by DOE. See Attachment 3 for specific requirements.			
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(10)	(10) Facility design must also be integrated with other design requirements, as applicable, including explosive safety, industrial safety, and nuclear explosive safety (if applicable).	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL,T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(a)	(a) choosing an appropriate site;		T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(b)	(b) minimizing the quantity of material-at-risk;		MARVEL	105341: Material at Risk Minimization
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(c)	(c) applying conservative design margins;	The project should implement a margin management plan to document how conservatism will be included in the design.	MARVEL,T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(d)	(d) applying quality assurance;	The project will follow PDD-13000, Quality Assurance Program Description.	MARVEL,T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(e)	(e) using successive/multiple physical barriers for protection against radioactive releases (Note: If an exemption to having multiple barriers is required, it is the responsibility of the Head of Departmental Element to approve, or disapprove, the exemption for not including multiple physical barriers);		MARVEL,T-REXC	105343: Fuel and Core Fission Product Confinement 105329: Reactor Structure Fission Product Confinement 113979: Reactivity Control Fission Product Confinement
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(1)	(f) using multiple means to ensure safety functions are met by- 1 controlling processes;		MARVEL	104513: Reactor Parameter Monitoring 104515: System Control for Normal Operating Conditions
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(2)	(f) using multiple means to ensure safety functions are met by- 2 maintaining processes in safe status;		MARVEL	104516: Automatic Reactor Shutdown
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(3)	(f) using multiple means to ensure safety functions are met by- 3 providing preventive and/or mitigative controls for accidents with the potential for radiological releases; and		MARVEL	104518: Postulated Accident Scram
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(4)	(f) using multiple means to ensure safety functions are met by- 4 providing means for monitoring facility conditions to support recovery from upset or accident conditions;		MARVEL,T-REXC	104517: Operator Communication

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(5)	(f) using multiple means to ensure safety functions are met by- 5 using equipment in combination with administrative controls that- a restrict deviation from normal operations; b monitor facility conditions during and after an event; and c provide for response to accidents to achieve a safe condition;	Equipment requirements are covered in subsections 1-4. The use of administrative controls is governed by DOE-STD-1186.	MARVEL,T-REXC	112237: SDS-119 {LINK id=112237 uri=https://elm.de.inl.gov/rm/resources/TX_zWH8Fuk2Ee2UDJLskaYjCQ}
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(2)(f)(6-7)	(f) using multiple means to ensure safety functions are met by- 6 providing means to monitor accident releases as required for emergency response (see DOE O 151.1D, Comprehensive Emergency Management System, for detailed requirements); 7 establishing emergency plans for minimizing the effects of an accident (see DOE O 151.1D for detailed requirements).	SDS-119 cites DOE O 151.1D	T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(a)	(a) For a specific nuclear facility, the number, arrangement, and characteristics of confinement barriers as determined on a case-by case basis.		MARVEL,T-REXC	105343: Fuel and Core Fission Product Confinement 105329: Reactor Structure Fission Product Confinement 113979: Reactivity Control Fission Product Confinement
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(b)	(b) The type, quantity, form, and conditions for dispersing the radioactive material in the confinement system design.		T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(3)(c)	(c) An active confinement ventilation system as the preferred design approach for nuclear facilities with potential for radiological release. Alternate confinement approaches may be acceptable if a technical evaluation demonstrates either that the alternate confinement approach results in very high assurance of the confinement of radioactive materials or that an active confinement system provides no benefits. Guidance for confinement ventilation systems and evaluation of the alternatives is provided in DOE Guide (G) 420.1-1A, Nonreactor Nuclear Safety Design Guide for Use with DOE O 420.1C, Facility Safety. Some facilities where the only radioactive hazard/material is tritium have determined there is no benefit from an active confinement ventilation system.		T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(a)	(a) facilitate safe deactivation, decommissioning, decontamination, and demolition at the end of facility life, including incorporation of design considerations during the operational period that facilitate future decontamination and decommissioning;		MARVEL,T-REXC	105357: Power Generation Maintenance and Replacement 105309: Reactivity Control Element Decommissioning 105345: Fuel and Core Decommissioning 105330: Reactor Structure Decommissioning 104783: Instrumentation Decommissioning
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(b)	(b) facilitate inspections, testing, maintenance, repair, and replacement of safety SSCs as part of a reliability, maintainability, and availability program with the objective of maintaining the facility in a safe state;		MARVEL,T-REXC	105356: Power Generation Inspection and Testing 104785: Instrumentation and Control Inspection and Testing 105331: Reactor Structure Inspection and Testing 105312: Reactivity Control Inspection and Testing
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(4)(c)	(c) keep occupational radiation exposures within regulatory limits, and as low as reasonably achievable;	Regulatory occupational exposure limits are found in 10 CFR 835. Those requirements provide more detail for the design.	MARVEL,T-REXC	105318: Shielding

Name	Regulatory Text	Implementation Statement	Project Allocation	MARVEL F&OR Requirements
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(5)	(5) Facility process systems must be designed to minimize waste production and mixing of radioactive and non-radioactive wastes.		MARVEL,T-REXC	
DOE O 420.1C Attachment 2 Chapter I Section 3.b.(7)	(7) Active safety class systems must be designed to meet single failure criterion.		MARVEL,T-REXC	105307: Reactivity Control Single Failure Criterion 104780: Instrumentation and Control Single Failure Criterion
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(2)(a)	(a) New facilities (non-relocatable) exceeding 5,000 sq. ft. of floor area must be of Type I or Type II construction, as defined in the applicable building codes.	Fire protection will be covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(2)(b)	(b) Automatic fire suppression systems must be provided throughout new facilities exceeding 5,000 sq. ft. of floor area or where a Maximum Possible Fire Loss (MPFL) exceeds $5.9 million (in 2018 dollars), unless a specific provision of an applicable NFPA code provides different criteria for coverage (such as elimination of sprinklers from a small closet).	Fire protection will be covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(2)(c)	(c) Automatic fire suppression systems must be provided throughout facilities in which any of the following conditions exist: 1 where required by safety basis document (for example, to prevent loss of safety functions or provide defense-in-depth); 2 significant life safety hazards; 3 where fire may cause unacceptable mission or program interruption if automatic fire suppression systems are not provided; 4 where a modification to an existing facility would cause the MPFL to exceed $5.9 million (in 2018 dollars) for the facility; or 5 where a modification to an existing facility results in facility floor area that exceeds 5,000 sq. ft.	Fire protection is covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(2)(d)	(d) For property protection, multiple fire protection approaches, such as a fire suppression system and a fire detection and alarm system, must be provided in areas where the MPFL exceeds $177 million (in 2018 dollars) (refer to DOE-STD-1066-2016).	Fire protection is covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(2)(e)	(e) For property protection, fire areas must be established such that the MPFL for each fire area does not exceed $412 million (in 2018 dollars). Fire walls or other separation approaches may be used to meet this requirement.	Fire protection is covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(a)	(a) Fire Suppression. The inadvertent operation or failure of fire suppression systems must not result in the loss of function of safety class or safety significant systems. (Note: This requirement addresses proper design of the fire suppression system to ensure it does not impact safety systems and is not intended to drive need for redundancy in safety significant system design.)	Fire protection is covered by T-REXC	T-REXC	

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DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(b)	(b) Fire Barriers. Complete fire-rated construction and barriers, commensurate with the applicable codes and/or safety basis requirements, must be provided to isolate hazardous areas and minimize fire spread and loss potential consistent with limits as established in this chapter. Fire barrier locations and construction must be documented.	Fire protection is covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(c)	(c) Fire Detection. Automatic fire detection must be provided to the extent required by applicable industry codes and standards.	Fire protection is covered by T-REXC	T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(d)	(d) Life Safety. Requirements for life safety and means of egress are provided in 10 CFR Part 851. Other codes and standards, such as the International Building Code (IBC), and NFPA 101, Life Safety Code, may also be applicable.	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL,T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(e)	(e) Water Supply and Distribution. A reliable and adequate water supply and distribution system must be provided for fire suppression, as documented through appropriate analysis.		T-REXC	
DOE O 420.1C Attachment 2 Chapter II Section 3.c.(3)(f)	(f) Emergency Notification. A means to notify responders and building occupants of a fire must be provided (e.g., fire alarm signaling system and/or site-wide mass notification capabilities for major incidents affecting the site).		T-REXC	

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DOE O 420.1C Attachment 2 Chapter IV Section 3.a-c	a. General. Facilities must be designed, constructed, maintained, and operated to ensure that SSCs will be able to perform their intended safety functions effectively under the combined effects of NPH and normal loads defined in the applicable building codes contained in facilities' CORs. Nuclear facility safety functions that the SSCs must perform during and after an NPH event must be defined in the facility's safety basis documentation. Safety functions include: (1) confinement/containment of hazardous materials; (2) protection of occupants and co-located workers of the facility and the public; (3) continued operation of essential facilities and equipment; (4) safe shutdown of hazardous facilities and equipment; and (5) maintenance of personnel access to areas needed for responding to accidents during NPH events. b. NPH Design Criteria. The design of new facilities and major modifications must be developed in accordance with the applicable requirements and criteria contained in DOE-STD-1020-2016, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities. (Note: Requirements for non-nuclear facilities are described in Section 2.2 of DOE-STD-1020-2016.) c. NPH Accident Analysis. The NPH analysis supporting design and construction of facilities and safety SSCs must be documented and include evaluation of: (1) potential damage to and failure of safety SSCs resulting from both direct and indirect NPH events; and, (2) common cause/effect and interactions resulting from failures of other nearby facilities or other SSCs in the same facility caused by or induced by an NPH event.		MARVEL,T-REXC	105339: Fuel and Core Seismic Design 104526: Instrumentation and Control Seismic Design 105305: Reactivity Control Seismic Design 105327: Reactor Structure Seismic Design
DOE O 420.1C Attachment 2 Chapter IV Section 3.e	e. Seismic Detection. DOE sites with nuclear or hazardous materials must have instrumentation or other means to detect and record the occurrence and severity of seismic events.		T-REXC	
DOE O 420.1C Attachment 3 Section 3.a.(1)	(1) Conservative Design Margin. Safety SSCs must be designed with appropriate margins of safety, as defined in applicable DOE or industry codes and standards.		MARVEL	105336: Decay Heat Removal Through Reflectors 105317: Decay Heat to Ultimate Heat Sink 105303: Decay Heat Removal Through Reactivity Control Elements 105338: Fuel and Core Design for Operating Environment 105315: Core Heat Removal 105335: Fuel Matrix Heat Transfer

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DOE O 420.1C Attachment 3 Section 3.a.(2)(a)	(a) Safety class SSCs must be designed to perform all safety functions with no failure mechanism that could lead to common cause failures under postulated service conditions. The requirements of IEEE 323-2003 (R2008), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations, must be used to ensure environmental qualifications of safety class SSCs, unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-STD-1189-2016.		MARVEL	105310: Reactivity Control SR Qualification 104782: Instrumentation and Control SR Qualification
DOE O 420.1C Attachment 3 Section 3.a.(2)(a)	(a) The single failure criterion, requirements, and design analysis identified in Institute of Electrical and Electronics Engineers (IEEE) 379-2014, IEEE Standard for Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems, must be applied to safety class SSCs during the design process as the primary method of achieving reliability, unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-Standard (STD)-1189-2016. ANSI/ANS 58.9-2002 (R2015), Single Failure Criteria for LWR Safety-Related Fluid Systems, may be used in defining the scope of active safety class mechanical SSCs.		MARVEL,T-REXC	104780: Instrumentation and Control Single Failure Criterion 105307: Reactivity Control Single Failure Criterion
DOE O 420.1C Attachment 3 Section 3.a.(2)(b)	(b) Safety significant SSCs located in a harsh environment must be evaluated to establish qualified life. This may be accomplished using manufacturers' recommendations or other appropriate methods.		MARVEL	105326: Reactor Structure Design for Operating Environment 105304: Reactivity Control Design for Operating Environment 105338: Fuel and Core Design for Operating Environment 104525: Instrumentation and Control Design for Operating Environment 105353: Power Generation Design for Operating Environment
DOE O 420.1C Attachment 3 Section 3.a.(2)(b)	(b) Safety significant SSCs must be designed to reliably perform all their safety functions. This can be achieved through a number of means, including use of redundant systems/components, increased testing frequency, high reliability components, and diagnostic coverage (e.g., on-line testing; monitoring of component and system performance; and monitoring of various failure modes). DOE-STD-1195-2011, Design of Safety Significant Safety Instrumented Systems Used at DOE Nonreactor Nuclear Facilities, provides an acceptable method for achieving high reliability of safety significant safety instrumented systems.		MARVEL	104781: Independence from Control System

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DOE O 420.1C Attachment 3 Section 3.a.(3)	(3) Safe Failure Modes. The facility design must provide reliable safe conditions and sufficient confinement of hazardous material during and after all design basis accidents (DBAs). At both the facility- and SSC-level, the design must ensure that most probable modes of failure (e.g., failure to open versus failure to close) will increase the likelihood of a safe condition.		MARVEL	104527: Instrumentation and Control Fail Safe State 105306: Reactivity Control Fail Safe State
DOE O 420.1C Attachment 3 Section 3.a.(4)	(a) Support SSCs must be designed as safety class or safety significant SSCs if their failures prevent safety SSCs or specific administrative controls (SACs) from performing their safety functions. (b) Interfaces-such as pressure retention boundaries, electrical supply, instrumentation, cooling water, and other support systems-may exist between safety SSCs and non-safety SSCs. These interfaces must be evaluated to identify SSC failures that would prevent safety SSCs from performing their intended safety function. IEEE 384-2008, IEEE Standard Criteria for Independence of Class IE Equipment and Circuits, must be used for physical and electrical separation methods, including the use of separation distance, barriers, electrical isolation devices, or any combination thereof, unless another applicable standard is approved by DOE in accordance with the process for obtaining DOE review and approval of the applicability of codes and standards as described in DOE-STD-1189-2016. This application includes a design to ensure that both direct and indirect impacts of DBAs (e.g., fire, seismic) will not cause failure of safety functions.		MARVEL	104781: Independence from Control System
DOE O 420.1C Attachment 3 Section 3.a.(5)	(5) Protection Against Fire. Safety class systems must be designed with redundancy or other means, such that safety function is maintained for any postulated fire events that credit the safety class systems.		MARVEL	105328: Reactor Structure Fire Protection 104784: Instrumentation and Control Fire Protection
DOE O 420.1C Attachment 3 Section 3.b	The selection and use of an appropriate set of applicable codes and standards establishes design criteria to provide assurance that the SSCs are designed to reliably perform their intended functions. The DOE technical standards and industry codes and standards identified below, which are widely used for nuclear facility design and construction, must be evaluated for applicability. DOE technical standards and industry codes and standards are considered applicable when they provide relevant design requirements for the safety SSCs that are being designed (i.e., they provide design requirements that are needed to ensure that desired SSC functions are achieved, and these requirements are appropriate for the design materials, configuration, and service conditions). Further, the use of specific codes and	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	

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	standards may be directed by the DOE Head of Field Element. (Note: The stated applicability of industry codes and standards (e.g., for nuclear reactors) should not be used to narrowly interpret relevancy for SSC design.)Before using these codes and standards, their application to specific DOE design(s) must be reviewed. Once a code or standard is identified as applicable, the applicable requirements (i.e., mandatory statements) must be applied in the design. The process for obtaining DOE review and approval of the applicability of codes and standards is described in DOE-STD-1189-2016.The Safety Design Strategy developed in accordance with DOE-STD-1189-2016 may be used to specify provisions for relief (exemptions and equivalencies) from identified, applicable design and construction codes and standards. If the Safety Design Strategy is not used to specify relief provisions, the process for obtaining relief (i.e., equivalencies or exemptions) from applicable requirements in applicable DOE technical standards and industry codes and standards is described in Attachment 1 of DOE O 420.1C. (Note: Relief is not necessary for requirements within an applicable industry code or standard where the requirements are not relevant to the design or construction. Relief from Order 420.1C requirements, including requirements to follow invoked standards, would still be required to follow Attachment 1, Section 2.a, unless the requirements specifically relate to satisfying DOE technical standards and industry codes and standards that have been identified as applicable.)The set of codes and standards identified below is not meant to be all-inclusive. It is expected that design of SSCs will require selection of additional codes and standards beyond those identified below. For example, unique design features, detailed design considerations, and release of advancements may drive selection of additional codes and standards. Facility designers must identify the complete set of codes and standards necessary to meet the general design criteria identified above (see also Attachment 4 of DOE O 420.1C for additional codes and standards).			
DOE O 420.1C Attachment 3 Section 3.b.(1)	(1) Structural. Table 1 provides relevant codes and standards. Attachment 2, Chapter IV of DOE O 420.1C provides additional natural phenomena hazards (NPH) design requirements. Note: See DOE-STD-1020-2016, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities, for further discussion on selection and use of codes for structural design of SSCs.	See the MARVEL Code of Record for the applicable codes and standards. ACI-318 and ACI-349 do not apply to the MARVEL project because there is no concrete in the design of MARVEL.	MARVEL	

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DOE O 420.1C Attachment 3 Section 3.b.(2)	(2) Mechanical and Process Equipment. Table 2 provides relevant codes and standards.	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	
DOE O 420.1C Attachment 3 Section 3.b.(3)	(3) Ventilation. Table 3 provides relevant codes and standards. Appendix A of DOE Guide (G) 420.1-1A, Nonreactor Nuclear Safety Design Criteria for use with DOE O 420.1C, Facility Safety, and DOE-HDBK-1169-2003, Nuclear Air Cleaning Handbook, provide guidance for confinement ventilation systems design and performance criteria. Alternate methods must be approved by DOE Heads of Field Element	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	
DOE O 420.1C Attachment 3 Section 3.b.(4)	(4) Mechanical Handling Equipment. Table 4 provides relevant codes and standards.	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	
DOE O 420.1C Attachment 3 Section 3.b.(5)	(5) Electrical. Tables 5 and 6 provide relevant codes and standards. Note: ANSI/IEEE standards, below, define requirements for the manufacturing, installation, and testing of commercial reactor Safety-Class 1E electrical systems and components. While these requirements may not be directly applicable to nonreactor nuclear facilities, these standards contain useful and significant information that should be considered.	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	
DOE O 420.1C Attachment 3 Section 3.b.(6)	(6) Instrumentation, Control, and Alarm Systems. The design of safety class instrumentation and control systems must incorporate sufficient independence, redundancy, diversity, and separation to ensure that all safety-related functions associated with such equipment can be performed. Safety significant components must be evaluated as to the need for redundancy on a case-by-case basis. DOE-STD-1195-2011 provides an acceptable method for achieving high reliability of safety significant safety instrumented systems. Table 7 provides relevant codes and standards. The codes and standards for electrical systems (in Tables 5 and 6) may also be applicable to design of instrumentation and control systems and need to be evaluated in this context.	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	
DOE O 420.1C Attachment 3 Section 3.b.(7)	(7) Fire Protection Systems. DOE-STD-1066-2016, Fire Protection, provides acceptable methods for the design of fire protection systems. Design requirements for safety class and safety significant fire barriers, water supplies, and wet pipe sprinkler systems are provided in Appendix A of DOE-STD-1066-2016. Fire protection system designs are also required to address the applicable design requirements for similar safety systems provided in this attachment	See the MARVEL Code of Record for the applicable codes and standards.	MARVEL	