INL/MIS-24-78458-Revision-0

TFR-2578 MARVEL Reactivity Control System (RCS)

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Changing the World's Energy Future

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Idaho National Laboratory

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Technical and Functional Requirements

MARVEL Reactivity Control System (RCS)

Idaho National Laboratory

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CONTENTS

1. INTRODUCTION

1.1 System Identification

This document contains the Level 3 requirements associated with the subsystems of the Reactivity Control System (RCS) in the Microreactor Applications Research Validation and Evaluation (MARVEL) project:

- Drum and Rod Forcing Subsystem (DFS)
- Drum and Rod Structures Subsystem (DSS)
- Drum and Rod Neutronics Subsystem (DNS)
- Drum and Rod Position Measurement Subsystem (DPMS)

The RCS subsystems are responsible for communicating with the Instrumentation and Control System (ICS) to translate operator commands into reactivity control element movement.

1.2 Limitations of the T&FR

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

1.3 Ownership of the T&FR

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

1.4 Definitions/Glossary

Cold Zero Power	The normal operating condition where the reactor k^{eff} is equal to one but the reactor is not adding an appreciable amount of heat to cause a significant amount of temperature feedback.
Hard Stop	A physical design feature used to limit the maximum degree the control drum can be rotated from the shutdown position.
Hot Full Power	The normal operating condition where the reactor primary coolant is at its highest nominal temperature and the reactor is producing power at its upper design limit.
Hot Standby	The normal operating condition where the primary coolant is kept hot enough, using nuclear power, to maintain the lead secondary coolant above its freezing temperature.
Shutdown Position	The position of the control drum when the poison section of the drum is fully facing the reactor core.

1.5 Acronyms

ALARA	As Low As Reasonably Achievable
BOL	Beginning of Life
CH	Contact Handled
CIA	Central Insurance Absorber
COR	Code of Record
CZP	Cold Zero Power
DFS	Drum and Rod Forcing Subsystem
DiD	Defense-in-Depth
DNS	Drum and Rod Neutronics Subsystem
DPMS	Drum and Rod Position Measurement Subsystem
DSS	Drum and Rod Structures Subsystem
D&D	Deactivation & Decommissioning
ECAR	Engineering, Calculation, and Analysis Report
HFP	Hot Full Power
I&C	Instrumentation and Control
LLW	Low-Level Waste

MARVEL	Microreactor Applications Research Validation and Evaluation
MBSE	Model-Based Systems Engineering
MLLW	Mixed Low-Level Waste
NSR	Non-Safety Related
NSR-AR	Non-Safety Related with Augmented Requirements
PDSA	Preliminary Documented Safety Analysis
RCS	Reactivity Control System
RH	Remote Handled
RPS	Reactor Protection Subsystem
SDD	System Design Description
SR	Safety Related
SSCs	Structures, Systems, and Components
TOP	Transient Overpower
TREAT	Transient Reactor Test Facility
T-REXC	TREAT Facility Micro-Reactor Experiment Cell

2. GENERAL OVERVIEW

2.1 System Functions

2.1.1 DFS Functions

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

Control Drum-related functions:

DFS.1: Receive Control Drum Position Command from Control System

DFS.2: Apply Mechanical Torque to Control Drum Shaft

DFS.3: Reduce Mechanical Torque to Control Drum Shaft

DFS.4: Limit Speed of Control Drum Motor

DFS.5: Disengage Control Drum Shaft

DFS.6: Force Control Drums to Shutdown Position

DFS.7: Reduce Control Drum Impact on Hard Stops

CIA Rod-Related Functions

DFS.8: Receive CIA Rod Position Command from Control System

DFS.9: Apply Force to CIA Rod Shaft

DFS.10: Reduce Force Applied to CIA Rod Shaft

DFS.11: Limit Speed of CIA Rod Motor

DFS.12: Disengage CIA Rod Shaft

DFS.13: Insert CIA Rod to Shutdown Position

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

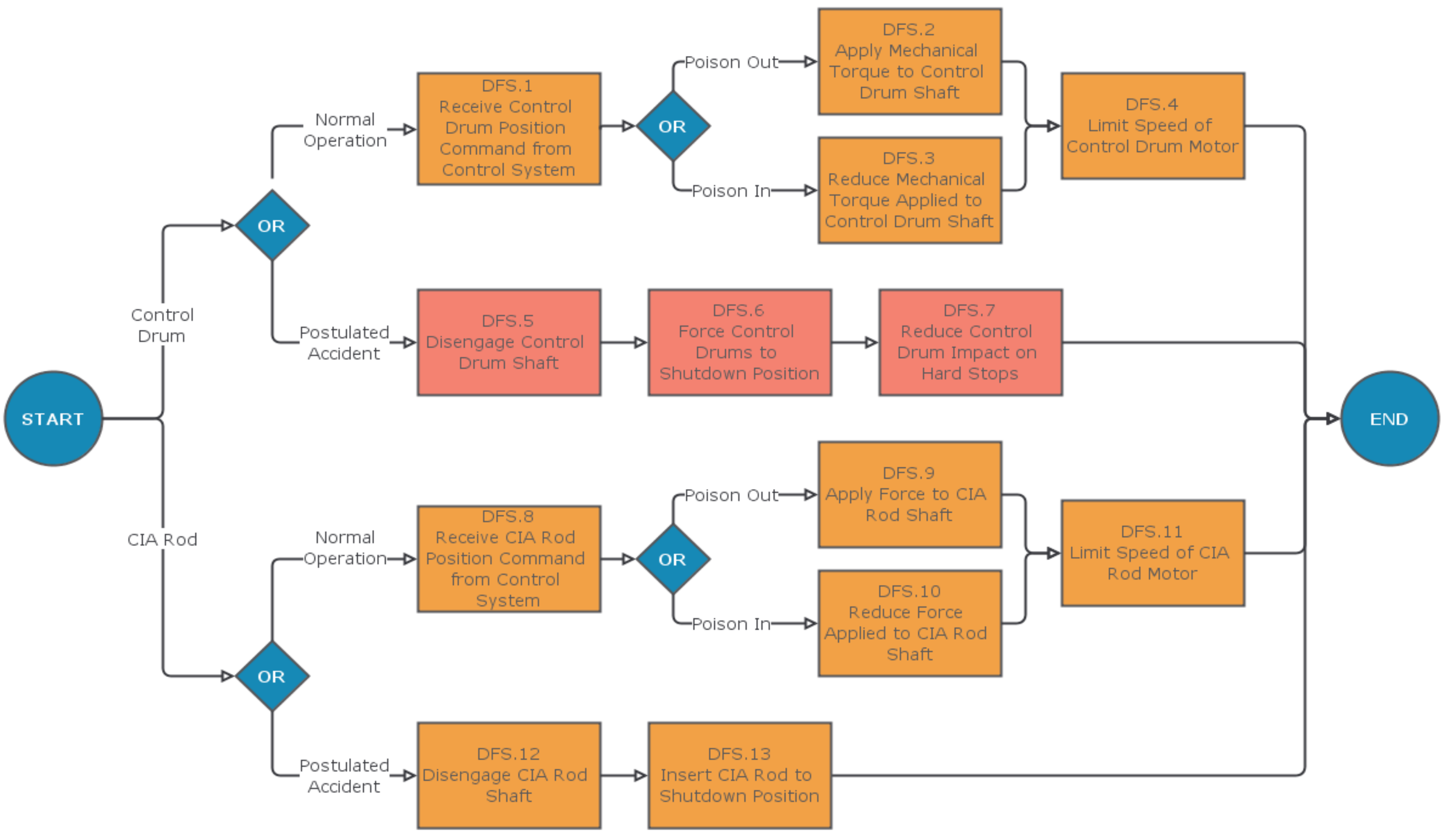

Figure 1. Drum and Rod Forcing Subsystem Functional Diagram.

2.1.2 DSS Functions

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

DSS.1: Provide Structural Link Between Forcing and Neutronic Components

DSS.2: Limit Maximum Rotation of Control Drums

DSS.3: Limit Maximum Hight of CIA Rod

DSS.4: Support Leak Prevention Through Secondary Confinement Boundary

DSS.5: Provide Positive Locking in the Shutdown Position

2.1.3 DNS Functions

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

DNS.1: Provide Positive Reactivity Contribution to Sustain Power Operations

DNS.2: Provide Negative Reactivity Contribution to Shutdown Reactor

DNS.3: Enable Initial Core Reactivity Adjustment

DNS.4: Enable Heat Transfer from Primary Coolant Boundary to Guard Vessel

2.1.4 DPMS Functions

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

DPMS.1: Measure When Control Drum is at the Maximum Reactivity Angle

DPMS.2: Measure When Control Drum is at the Shutdown Angle

DPMS.3: Measure Control Drum Angle over Full Range of Motion

DPMS.4: Measure When CIA Rod is at the Maximum Reactivity Height

DPMS.5: Measure When CIA Rod is at the Shutdown Height

DPMS.6: Measure CIA Rod Height over Full Range of Motion

DPMS.7: Display Limit Switch Indication in TREAT Control Room

DPMS.8: Transmit Reactivity Control Element Position Data to Control System

DPMS.9: Transmit Reactivity Control Element Position Data to DFS

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

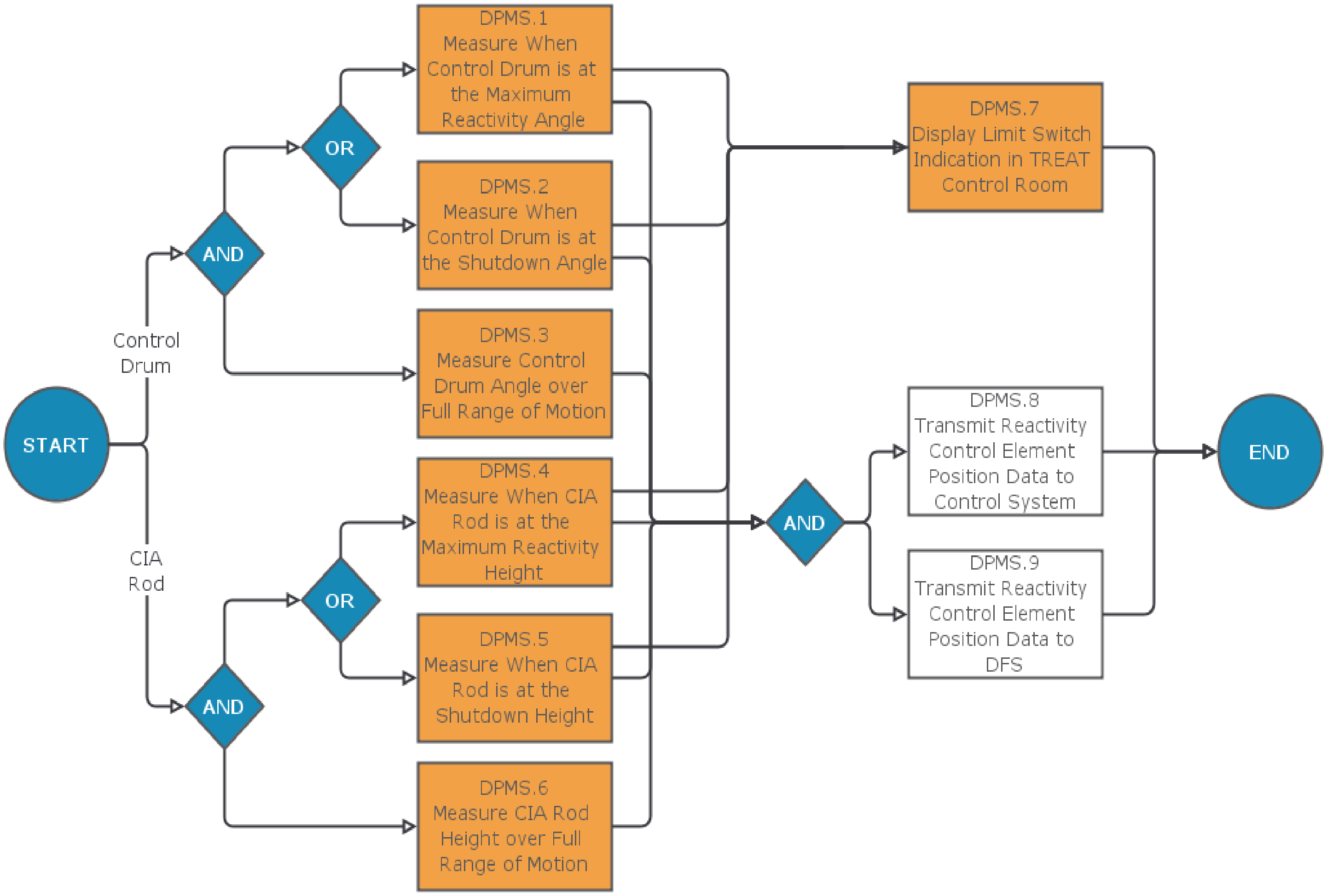

Figure 2. Drum Position Measurement Subsystem Functional Diagram.

2.2 System Classification

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

Table 1. RCS Subsystem Classifications.

Acronym	Subsystem	Classification
DFS	Drum and Rod Forcing Subsystem	Safety Related (SR)
DSS	Drum and Rod Structures Subsystem	SR
DNS	Drum and Rod Neutronics Subsystem	SR
DPMS	Drum and Rod Position Measurement Subsystem	Non-Safety Related-Augmented Requirements (NSR-AR)

2.3 Basic Operational Overview

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

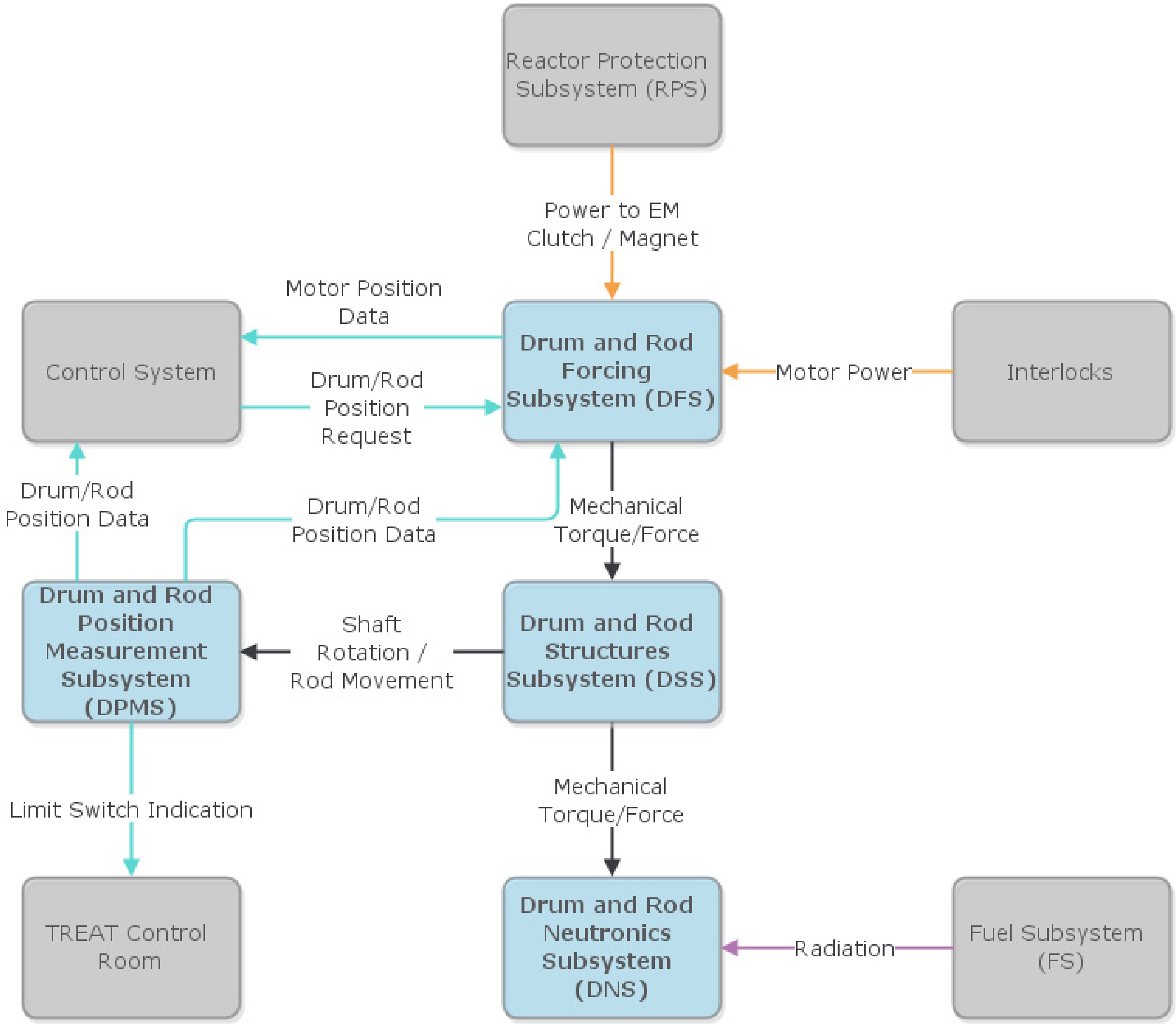

Figure 3. Reactivity Control System Architecture and Interfaces.

2.3.1 DFS Basic Operational Overview

Within the control drum subsystems, the DFS consists of servomotors and motor controllers that receive a position request from the control system and motor power via the interlocks and translate the electrical energy into mechanical torque on the drum structure or mechanical force on the central insurance absorber (CIA) rod. The DFS reports back the motor position from the resolver to the control system. An electromagnetic clutch is also provided within the DFS that is energized by the interfacing Reactor Protection System (RPS). Upon detection of an accident condition, the RPS de-energizes the clutch and the drums spring back to the shutdown position.

2.3.2 DSS Basic Operational Overview

The DSS provides the structural link between the DFS and the neutronics portion of the drum or CIA rod sitting within the core region (DNS subsystem). The drum or rod cage, shaft, and shaft assembly are capable of supporting the imposed forces while providing a reliable reference frame. The DSS also contains a hard stop designed to limit the excess reactivity by limiting the maximum angle at which the drum can be turned to or the maximum height the CIA rod can be withdrawn to. The DSS also contains a seal where the shaft penetrates the guard vessel pressure boundary.

2.3.3 DNS Basic Operational Overview

The DSS is connected to the DNS which provides either reflection of radiation back into the core region via BeO plates or absorption of radiation via B4C poison plates. These plates are stacked into a cylindrical drum that rotates adjacent to the core region outside the primary coolant boundary.

2.3.4 DPMS Basic Operational Overview

The DPMS consists of limit switches and potentiometers that more directly report the position of each control drum or the CIA rod to the DFS motor controllers and the control system. The DPMS also provides direct limit switch indication in the TREAT control room, separately from the control system and HMI.

3. REQUIREMENTS AND BASES

3.1 Requirements

This section provides the requirements that must be met in the system design and will require design verification. The MARVEL project requirements are stored in the IBM DOORS Next software tool. This software was used to generate this document. Therefore, each requirement has an unique number in brackets [ ] to the left of the requirement used to identify the requirement in the database and to provide a hyperlink back to the software. Each requirement also includes a bolded title summarizing the concept and a rationale statement in italics explaining where the requirement comes from or why it provides value. Finally, the links within the requirements database showing how requirements relate to one another are displayed beneath the rationale. The Level 3 requirements in this document are derived from the Level 2 requirements contained in FOR-868, “Microreactor Applications Research Validation and Evaluation (MARVEL)

Project," and FOR-684, "Transient Reactor Test (TREAT) Facility Micro-Reactor Experiment Cell (T-REXC)" The calculational and design documents that verify that these requirements have been met by the design are listed in VM-118 "MARVEL Design Verification Matrix."

3.2 Bases

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

3.3 References

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

3.4 General Requirements

3.4.1 System Functional Requirements

3.4.1.1 DFS Functional Requirements

[111787] Reactivity Control Element Movement Capability: The DFS shall be capable of providing the mechanical torque or force needed to overcome the resistance of the control drum or CIA rod structures and move the reactivity control element in the direction demanded by the motor controller.

Rationale: The DFS provides the torque or force needed to move the control drums and CIA rod to their desired position, based on input from the control system.

Derived By: [105299] Reactivity Control Element Movement

Linked From: DFS.2, DFS.3

[111788] Control Drum Rotation Speed Limit: The DFS shall not be capable of moving the control drum at a rotational velocity exceeding 1.7 degrees per second.

Rationale: Limiting the possible reactivity insertion serves as DID for the Transient Overpower (TOP) condition which assumes an instantaneous reactivity insertion and the safety related hard stop. A reasonable speed limit of 1.7 deg/s allows for anticipated fast and slow speeds (0.41 to 1.03 deg/sec for fast and 0.02 to 0.3 deg/sec for slow) with additional buffer for adjustment by the software. The speed is based on a reactivity insertion rate of around 8.3 cents/sec in the most reactive drum location with a conversion of 4.87 cents/degree. The anticipated fast and slow speeds correspond to around 2 to 5 cents/sec and 0.1 to 1.5 cents/sec, where are selected based on human operator performance and may be adjusted using software.

Derived By: [105300] Reactivity Change Control

Linked From: DFS.4

[111789] Control Drum Rotation Precision: The DFS shall be capable of moving the control drum to the operator-requested position with an angular precision of at least 1 degrees.

Rationale: The precision of 1 degrees correlates to around 4.87 cents (per ECAR-6099 Rev. 0) in the most reactive location. The movement precision is limited by the backlash and twist which is about 1 degree.

Derived By: [105299] Reactivity Control Element Movement

Linked From: DFS.1

[116392] Passive Control Drum Negative Reactivity Insertion: The DFS shall passively force the control drums to the full shutdown position upon de-energization of the electromagnetic clutch.

Rationale: Springs provide a passive means to ensure the drums return to the shut-down position when the clutch releases.

Derived By: [105302] Negative Reactivity, [105306] Reactivity Control Fail Safe State

Linked From: DFS.6

[116402] Scram Impact on Hard Stops: The DFS shall include features to limit the mechanical impact of the control drum structures on the hard stops during a scram.

Rationale: During a scram, the control drum will rapidly rotate to the shutdown position. The stored energy in the control drum spring has the potential to challenge the integrity of the hard stop or the control drum structure itself.

Derived By: [105302] Negative Reactivity

Linked From: DFS.7

[111794] CIA Rod Movement Capability: The DFS shall be capable of providing the mechanical force needed to move the CIA rod in the direction demanded by the motor controller.

Rationale: The DFS provides the force needed to move the CIA rod to the desired position, based on input from the control system.

Derived By: [105299] Reactivity Control Element Movement

Linked From: DFS.9, DFS.10

[111795] CIA Rod Movement Speed Limit: The DFS shall limit CIA rod movement to a speed correlating to 5 cents per second at the most reactive position.

Rationale: Limiting the speed of the CIA rod mitigates the possibility of abnormal transients and provides a DiD feature in addition to the hard stop.

Derived By: [105300] Reactivity Change Control

Linked From: DFS.11

[111796] CIA Rod Movement Precision: The DFS shall be capable of moving the CIA rod to the operator-requested position with a precision of at least 0.1 in.

Rationale: The precision of 0.1 inches correlates to around 0.75 cents in the most reactive location and is sufficient for fine tuning of the critical position based on experience.

Derived By: [105299] Reactivity Control Element Movement

Linked From: DFS.8

[116399] Passive CIA Rod Negative Reactivity Insertion: The DFS shall passively insert the CIA rod to the full shutdown position upon de-energization of the electromagnet.

Rationale: The negative reactivity insertion function should be passive to reduce the number of active safety systems.

Derived By: [105302] Negative Reactivity, [105306] Reactivity Control Fail Safe State

Linked From: DFS.13

3.4.1.2 DSS Functional Requirements

[111790] Maximum Control Drum Angle: The DSS shall provide a settable feature to limit the maximum rotation of the control drums.

Rationale: The hard-stops on the control drums limit the excess reactivity to less than the value specified in the accident analysis. The limiting step of $0.40 of reactivity insertion between the critical position and the hard stop were considered in ECAR-6332 Rev. 0.

Derived By: [105300] Reactivity Change Control

Linked From: DSS.2

[111797] Maximum CIA Rod Height: The DSS shall provide a settable feature to limit the maximum height of the CIA rod from its shutdown position.

Rationale: The hard-stop on the CIA rod limits the excess reactivity to less than the value specified in the accident analysis (ECAR-6440, ECAR-6332) and on the reactivity measurements determined during commissioning tests.

Derived By: [105300] Reactivity Change Control

Linked From: DSS.3

3.4.1.3 DNS Functional Requirements

[111801] Control Drum Negative Reactivity Worth: Two control drums shall together provide at least 2% of shutdown margin while in the shutdown position and the other two control drums are at the hard stop maximum reactivity angle.

Rationale: Having this negative reactivity worth in two control drums enables them to bring the reactor subcritical from hot full power conditions with the two other control drums stuck at the maximum reactivity positions and the CIA rod fully removed. This ensures that the system can meet the single failure criterion for SR systems. A shutdown margin of at least 2% is a generally acceptable value.

Derived By: [105302] Negative Reactivity, [105306] Reactivity Control Fail Safe State

Linked From: DNS.2

[111802] Control Drum Positive Reactivity Worth: The control drums shall collectively provide enough excess reactivity in the placement of the hard stops, to overcome the temperature feedback from CZP conditions and remain critical before the BeO2 is heats up.

Rationale: The control drums will gain reactivity as the BeO2 heats up. The hard stops should be placed such that criticality can be maintained after losing reactivity from the core heating up and before the BeO2 heats up.

Derived By: [105308] Reactivity Control for Startup

Linked From: DNS.1

3.4.1.4 DPMS Functional Requirements

[111791] Control Drum Maximum Angle Signal: The DPMS shall provide a signal to the control system and the DFS when the control drum reaches the hard stop angle.

Rationale: This is an indication to the operator that the control drums have reached their full out position at the hard stop and are providing maximum reactivity insertion.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.1

[111792] Control Drum Shutdown Angle Signal: The DPMS shall provide a signal to the control system and the DFS when the control drum reaches the shutdown position.

Rationale: The full shutdown signal helps the operator confirm that the control drum is in the shutdown position and is an important parameter for post-accident monitoring indication. This also prevents over-rotation of the control drum.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.2

[111601] Limit Switch Indication: The DPMS shall provide control drum and CIA rod limit switch indication in the control room.

Rationale: The limit switch indication is an important post-accident monitoring parameter to confirm that the reactivity control elements are in the shutdown position.

Derived By: [104517] Operator Communication

Linked From: DPMS.7

[111793] Control Drum Angular Position Measurement: The DPMS shall be capable of measuring the control drum angular position over its full range of motion with a precision of at least 0.1 degrees and relay the information to the control computer and DFS.

Rationale: The precision of 0.1 correlates to approximately 1.25 cents (per ECAR-6099 Rev. 0) and is a sufficient for fine tuning of the critical position based on experience. The drum position is an important parameter for use by the operator and control system.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.3, DPMS.8, DPMS.9

[111798] CIA Rod Maximum Height Signal: The DPMS shall provide a signal to the control system and the DFS when the CIA rod reaches the hard stop height.

Rationale: This is an indication to the operator that the CIA rod has reached its full out position at the hard stop and are providing maximum reactivity insertion.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.4

[111799] CIA Rod Shutdown Height Signal: The DPMS shall provide a signal when the CIA rod is at the shutdown height.

Rationale: The full shutdown signal helps the operator confirm that the CIA rod is in the shutdown position and is an important parameter for post-accident monitoring indication.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.5

[111800] CIA Rod Position Measurement: The DPMS shall be capable of measuring the height of the CIA rod over its full range of motion with a precision of at least 0.1 inches and relay the information to the control computer and DFS.

Rationale: The precision of 0.1 inches correlates to just under 2 cent and is an arbitrary value for a rod that will be removed for most operations. The intended motion of the CIA rod is to be either inserted or fully removed.

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: DPMS.6, DPMS.8, DPMS.9

3.4.2 Subsystem and Major Components

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

3.4.3 Boundaries and Interfaces

Interface requirements with the ICS control system are covered in Section 3.4.1. However, the following diagram clarifies the system interfaces associated with control room display and which SSCs belong to which MARVEL subsystem.

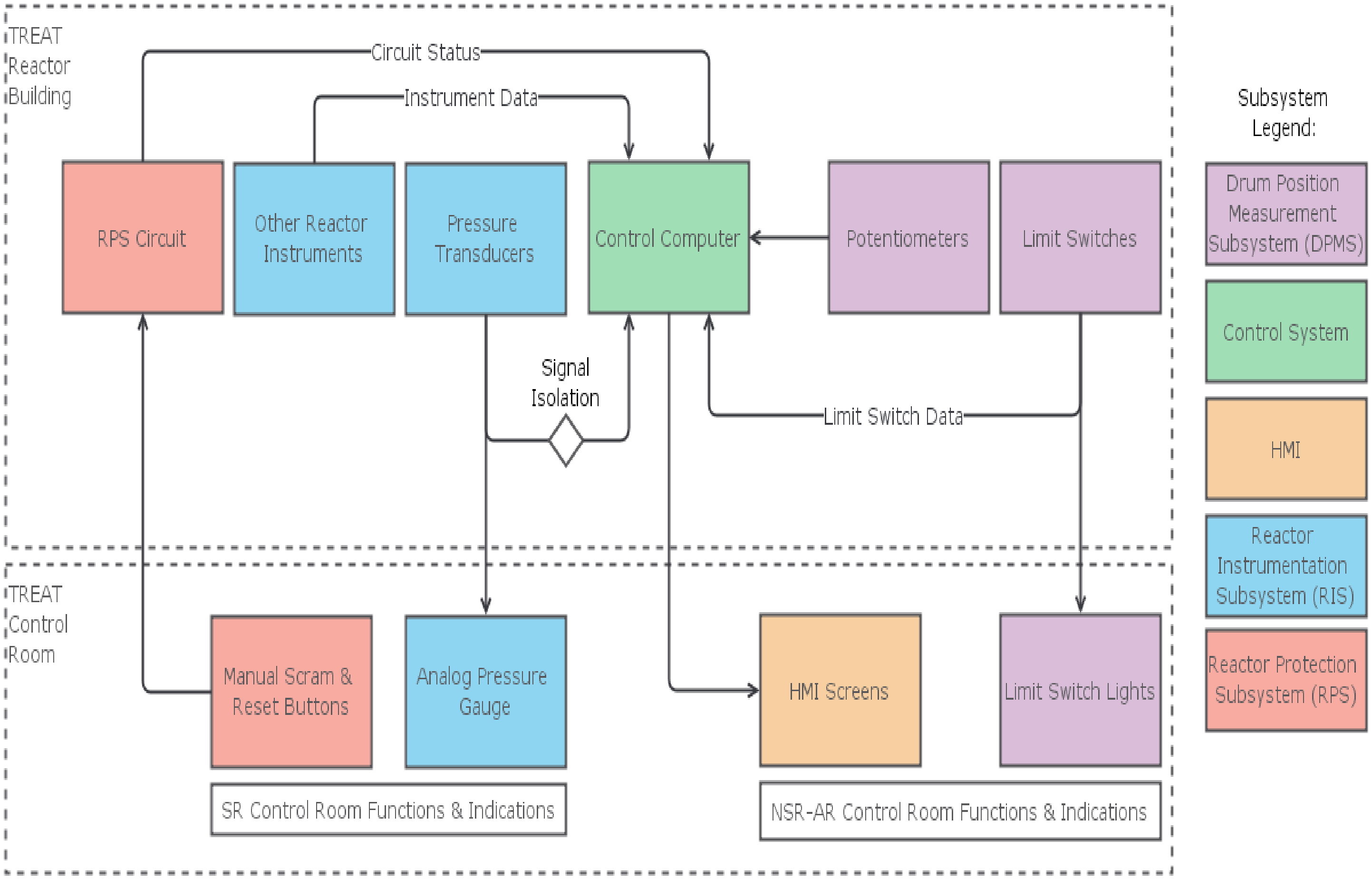

Figure 4. MARVEL Interfaces Associated with Control Room Display.

3.4.4 Code of Record

See the MARVEL Code of Record (COR) for the codes and standards applicable to the project.

3.4.5 Operability

[111803] Initial Core Reactivity Adjustment: The DNS shall provide sufficient worth per unit of length to enable the adjustment of the initial core reactivity using the CIA rod.

Rationale: This allows operators to finetune the reactivity of the core during startup to address dimensional and material property tolerances.

Derived By: [105308] Reactivity Control for Startup

Linked From: DNS.3

3.5 Specific Requirements

3.5.1 Radiation and Other Hazards

[111804] Waste Classification of Reactivity Control Equipment: All activated RCS SSCs shall be disposable as either Low-Level Waste (LLW) or Mixed Low-Level Waste (MLLW) at the end of their operating life.

Rationale: Disposing of equipment as LLW or MLLW simplifies the MARVEL D&D process and ensures that material can be dispositioned through existing disposition paths, either DOE or commercial sites. This is an assumption of the MARVEL environmental assessment, DOE/EA-2146, Section 3.7. Ideally this waste can be contact handled (CH) vs. remote handled (RH).

Derived By: [105309] Reactivity Control Element Decommissioning

3.5.2 As Low As Reasonably Achievable [ALARA]

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

3.5.3 Nuclear Criticality Safety

[111805] Locking Mechanism: Each control drum and the CIA rod shall have a mechanical locking mechanism capable of locking the equipment in the shutdown position.

Rationale: The locking mechanism is used to ensure subcriticality during fuel load by preventing control drum and CIA rod movement from the shutdown position and thus positive reactivity insertion.

Derived By: [105313] Reactivity Control Maintenance and Replacement

Linked From: DSS.5

3.5.4 Industrial Hazards

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

3.5.5 Operating Environment and Natural Phenomena

[111806] Radiation Environment for RCS Components in Guard Vessel: RCS SSCs installed within the guard vessel shall be capable of operating while absorbing a total integrated dose of 300MRad.

Rationale: Equipment must be designed to function in the environment in which it is installed. RCS components within the guard vessel will not be replaceable during the life of the reactor. This value is based on preliminary dose calculations near the reactivity control equipment surrounding the reactor barrel (33 to 57 cm from core center) and an operational life of 2 years of intermittent full power operations.

Derived By: [105304] Reactivity Control Design for Operating Environment

[111807] Radiation Environment for RCS Components above Upper Shield: RCS SSCs (motors, switches, rails, etc.) installed above the upper confinement boundary shall be capable of tolerating a radiation dose of at least 1000 RAD over their design lifetime.

Rationale: Equipment such as the drum actuators and T-REXC electronics are installed above the upper confinement space and must be protected from degradation. NRC RG 1.209 specifies a limit of 1,000 Rad for metal oxide semiconductor electronics qualified in a radiologically mild environment. NRC RG 1.89. has a limit of 1E4 rads for organics and general electrical equipment.

Derived By: [105304] Reactivity Control Design for Operating Environment

[111808] Reactivity Control Equipment in TREAT Temperature Environment: Reactivity control electronics installed outside T-REXC but within TREAT shall be able to operate in a temperature environment up to 30 deg C.

Rationale: Electronic equipment must be designed to function in the temperatures expected in the installed location.

Derived By: [105304] Reactivity Control Design for Operating Environment

[111810] Control Drum Thermal Environment: Portions of the control drums within the guard vessel (BeO and B4C components) shall be capable of maintaining their structural integrity at temperatures up to 1000ºF (538ºC).

Rationale: Equipment must be designed to function in the environment in which it is installed and the temperatures expected near the reactor vessel.

Derived By: [105304] Reactivity Control Design for Operating Environment

[111812] Control Drum and CIA Rod Material Stress: Reactivity control SSCs below the primary coolant distribution plenum shall be designed to withstand the material stresses (e.g., creep, swelling) imposed by their operating environment and thermal cycles of the reactor.

Rationale: The reactor will experience several thermal cycles throughout its operational life. SSCs located near the core region need to be designed to accommodate these fatigue cycles.

Derived By: [105304] Reactivity Control Design for Operating Environment, [105311] Structural Support for Reactivity Control Elements

Linked From: DSS.1

[111813] Control Drum Seismic Design Criteria: The components within the control drum-related subsystems (DSS and DNS) responsible for maintaining the control drums in the shutdown position once scrammed shall be designed to the seismic criteria of IBC-2015, using the response coefficients in Table 3-1 of DOE-STD-1020.

Rationale: The MARVEL reactor is categorized as NDC-2 per SDS-119. Per DOE-STD-1020, SDC-1 and SDC-2 SSCs shall be designed according to the criteria of IBC-2015, for Risk Category II and Risk Category IV facilities. The control drum will rotate to the shutdown position upon detection of the seismic p-wave. These structures must then hold this position upon the arrival of the s-wave.

Derived By: [105311] Structural Support for Reactivity Control Elements, [105305] Reactivity Control Seismic Design

Linked From: DSS.1

[111814] EM Clutch Environmental Qualification: The EM clutch shall be environmentally qualified to the expected conditions where it will be installed.

Rationale: The criteria of IEEE/IEC 60780-323 and according to the guidance given in IEEE 627 (and invoked by DOE O 420.1C for safety related components) are not applicable in the expected mild environment above the upper shield.

Derived By: [105307] Reactivity Control Single Failure Criterion, [105310] Reactivity Control SR Qualification

3.5.6 Human Interface Requirements

[111815] Locking Mechanism Human Interface: The control drum and the CIA rod mechanical locking mechanisms shall be designed to be accessible to personnel to install and remove the locks.

Rationale: Functions requiring an operator should be designed with human factors in mind.

Derived By: [105313] Reactivity Control Maintenance and Replacement

3.5.7 Specific Commitments

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

3.6 Engineering Discipline Requirements

3.6.1 Civil and Structural

[111816] Control Drum Seals: The control drum secondary confinement boundary seals shall support an integrated guard vessel leak rate of 1 x 10-4 std cc/sec during all postulated accident events.

Rationale: The seals form part of the secondary confinement boundary and support the fission product confinement function. The leak rate is derived from ASME BPVC Section V, Article 10 for mechanical joint leakage.

Derived By: [113979] Reactivity Control Fission Product Confinement

Linked From: DSS.4

3.6.2 Mechanical and Materials

[111817] Decay Heat Removal from Core Region via Control Drums: The control drums (along with other components between the PCS and the GVS) shall facilitate the removal of decay heat from the core region.

Rationale: The control drums surround the core barrel radially. These components must be designed to allow heat transfer out of the barrel and into the secondary confinement space in the event of a reactor shutdown.

Derived By: [105303] Decay Heat Removal Through Reactivity Control Elements

Linked From: DNS.4

3.6.3 Chemical and Process

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

3.6.4 Electrical Power

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

3.6.5 Instrumentation and Control

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

3.6.6 Computer Hardware and Software

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

3.6.7 Fire Protection

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

3.7 Testing and Maintenance Requirements

3.7.1 Testability

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

3.7.2 Inspections, Testing and Surveillances

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

3.7.3 Maintenance

[111818] Reactivity Control Equipment Removal and Replacement: Reactivity control electronics installed above the USS shall include provisions for remote removal and replacement such that maintenance can be performed using ALARA principles.

Rationale: Removal and replacement features support both replacement of failed components (e.g., motors and motor controllers) and ultimate D&D. A high bay crane in TREAT and remote tools can be used for removal and replacement operations in the event that worker dose limits would be exceeded by performing hands-on maintenance. Reference drawing 748740 for details on the crane hook. See ECAR-7447 for anticipated dose rates.

Derived By: [105312] Reactivity Control Inspection and Testing, [105309] Reactivity Control Element Decommissioning, [105313] Reactivity Control Maintenance and Replacement

3.8 Other Requirements

3.8.1 Security and SNM Protection

This section does not apply to this system.

3.8.2 Response to Alarms

[111819] Maximum and Minimum Angle Interlock: The DFS shall stop the control drum rotation upon receipt of the maximum (hard stop) or minimum (shutdown position) angle signal.

Rationale: Stopping the control drum rotation upon reaching the maximum angle limit switch is a defense in depth feature to the hard stop and obviates the need for operator reaction to the limit switch. Stopping rotation at the shutdown position prevents over-rotation of the control drum.

Derived By: [105300] Reactivity Change Control

[111820] Maximum and Minimum CIA Rod Height Interlock: The DFS shall stop the CIA rod movement upon receipt of the maximum (hard stop) or minimum (shutdown position) height signal.

Rationale: Stopping the CIA rod movement upon reaching the maximum height limit switch is a defense in depth feature to the hard stop and obviates the need for operator reaction to the limit switch. Stopping at the shutdown position prevents over-insertion.

Derived By: [105300] Reactivity Change Control

3.8.3 Special Installation Requirements

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

3.8.4 Reliability, Availability, and Preferred Failure Modes

[111821] Motor Overcurrent Prevention: The DFS shall passively prevent overcurrent to the motors and motor controllers of the control drums and the CIA rod.

Rationale: Overcurrent may be an indication of binding or similar beyond anticipated friction conditions.

Derived By: [105306] Reactivity Control Fail Safe State

[111822] Maximum Time for Immediate Negative Reactivity Insertion: Upon loss of power, the control drums and CIA rod shall be designed to passively insert negative reactivity within 3 seconds.

Rationale: Immediate negative reactivity insertion is required to shut down the reactor and maintain it in the shutdown condition following a postulated seismic event. SAR-420 Section 15.11.1 conservatively assumes the relative arrival time of the secondary and primary seismic waves is 3.53 seconds. Approximately 0.5 seconds is allocated to the scram electronics leaving 3 seconds for the drums to smoothly insert negative reactivity and prevent any damage to the drum from abrupt motion.

Derived By: [105306] Reactivity Control Fail Safe State

Linked From: DFS.5, DFS.12

3.8.5 Quality Assurance

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

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

4. APPENDICES

Appendix A, Source Documents

Appendix B, System Drawings and Lists

Appendix A Source Documents

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

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

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

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

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

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

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

SAR-420, "Transient Reactor Test (TREAT) Facility FSAR", Rev. 6, Idaho National Laboratory.

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

748740, Treat – TLHC Lifting Link – 60 Ton Crane Hook, Rev. 000, Idaho National Laboratory.

Appendix B System Drawings and Lists

See the Affected Documents List in EC-1756 for a full listing of MARVEL RCS drawings.