INL/MIS-24-78446-Revision-0

TFR-2574 MARVEL Instrumentation and Control System (ICS)

October 2023

Changing the World's Energy Future

Brandon L Moon

Idaho National Laboratory

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

INL/MIS-24-78446-Revision-0

TFR-2574 MARVEL Instrumentation and Control System (ICS)

Brandon L Moon

October 2023

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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

Document ID: TFR-2574
Revision ID: 1
Effective Date: 10/03/23

Technical and Functional Requirements

MARVEL Instrumentation and Control System (ICS)

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

CONTENTS

1. INTRODUCTION

1.1 System Identification

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

- Reactor Instrumentation Subsystem (RIS)
- Control System
- Reactor Protection Subsystem (RPS)
- Interlocks
- Human Machine Interface (HMI)

The ICS subsystems perform most monitoring and control functions for the MARVEL reactor and provide the link between the machine and the operator in the control room.

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 Instrumentation and Control System is responsible for the overall development and maintenance of the T&FR.

1.4 Definitions/Glossary

None at this time.

1.5 Acronyms

ALARA	As Low As Reasonably Achievable
CAN	Controller Area Network
CIA	Central Insurance Absorber
COR	Code of Record
CZP	Cold Zero Power

DFS	Drum and Rod Forcing Subsystem
DiD	Defense-in-Depth
DPMS	Drum and Rod Position Measurement Subsystem
D&D	Deactivation & Decommissioning
ECAR	Engineering, Calculation, and Analysis Report
ECS	Engine Cooling Subsystem
EM	Electromagnetic
HFP	Hot Full Power
HMI	Human Machine Interface
HRU	Heat Rejection Unit
ICS	Instrumentation and Control System
IHX	Intermediate Heat Exchanger
LOCA	Loss of Coolant Accident
MARVEL	Microreactor Applications Research Validation and Evaluation
MBSE	Model-Based Systems Engineering
NSR	Non-Safety Related
NSR-AR	Non-Safety Related with Augmented Requirements
PDSA	Preliminary Documented Safety Analysis
PGS	Power Generation System
RCS	Reactivity Control System
RIS	Reactor Instrumentation Subsystem
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
UPS	Uninterruptible Power Supply

2. GENERAL OVERVIEW

2.1 System Functions

2.1.1 RIS Functions

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

RIS.1: Measure Reactor Pressure(s)

RIS.2: Display Reactor Pressure(s) in Control Room

RIS.3: Measure Neutron Flux

RIS.4: Measure Primary Coolant Temperature(s)

RIS.5: Detect Primary Coolant Leaks into Guard Vessel

RIS.6: Detect Primary Coolant Leaks into CIA Housing

RIS.7: Detect Primary Coolant Leaks into IHXs

RIS.8: Measure Secondary Coolant Temperature

RIS.9: Receive Heater Control Signal

RIS.10: Heat Primary Coolant

RIS.11: Transmit Parameters to Control System

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.

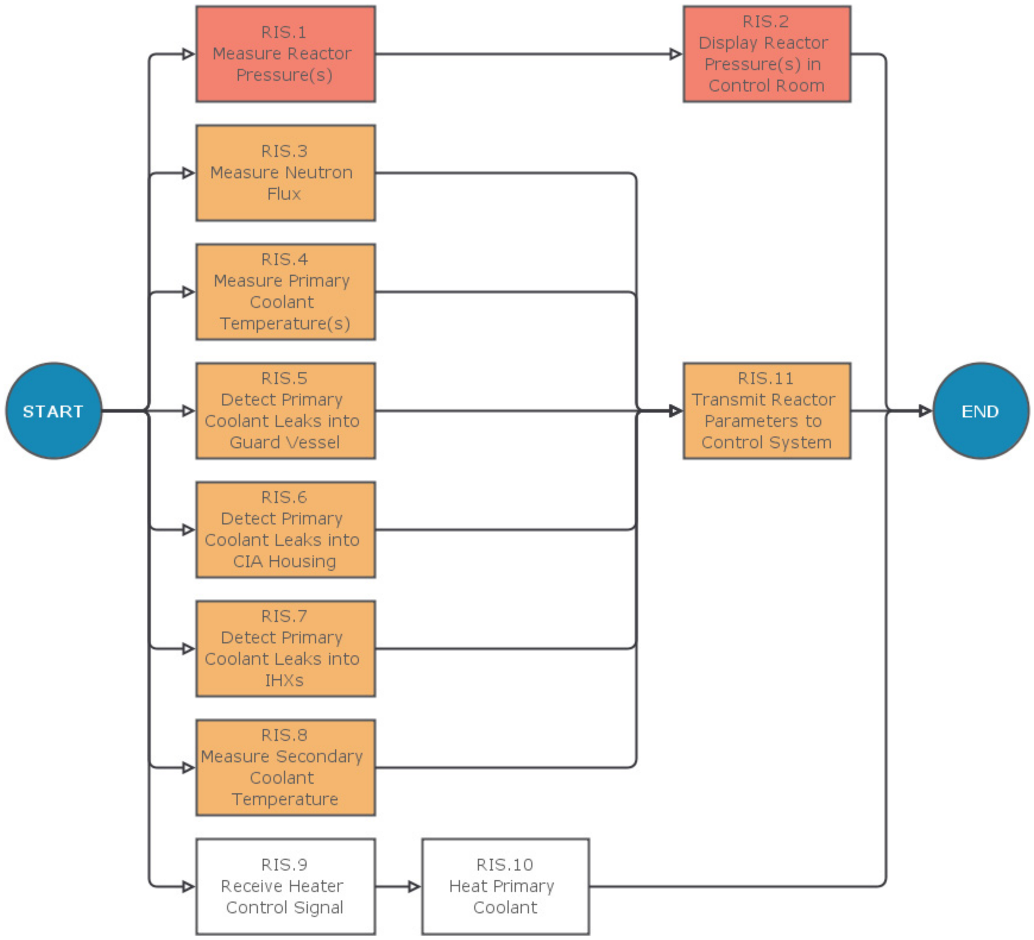

Figure 1. Reactor Instrumentation Subsystem Functional Diagram.

2.1.2 Control System Functions

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

Reactivity Control Element Movement Command Functions:

CS.1: Receive Reactivity Control Element Position Request

CS.2: Energize Corresponding Reactivity Control Element Relay

CS.3: Command Reactivity Control Element Motor Controller

CS.4: Generate Reactivity Control Element Request out of Range Warning

Reactivity Control Element Position Calculation Functions:

CS.5: Calculate Reactivity Control Element Position

CS.6: Generate Reactivity Control Element Position Warning

CS.7: De-Energize Reactivity Control Element Relays

Nuclear, Temperature, Pressure, and Leak Calculation Functions:

CS.8: Calculate Reactor Power Level

CS.9: Initiate Power Limit Trip

CS.10: Calculate Reactor Period and Reactivity

CS.11: Initiate Reactivity Limit Trip

CS.12: Calculate Reactor Temperatures

CS.13: Initiate High Core Outlet Temperature Trip

CS.14: Calculate Flow Direction

CS.15: Calculate Reactor Pressures

CS.16: Initiate Pressure out of Bounds Trip

CS.17: Monitor Leak Detector Signals

CS.18: Initiate NaK Leak Trip

Interface Communication Functions:

CS.19: Receive T-REXC Ventilation System Status

CS.20: Generate No Upper Confinement Ventilation Warning

CS.21: Monitor Current to Reactivity Control Elements

CS.22: Generate Current out of Bounds Alarm

CS.23: Receive Engine System Request from HMI

CS.24: Command Engine Cooling System Components

CS.25: Prevent Inadvertent Engine Operation

CS.26: Receive Engine Instrument Data

CS.27: Generate Engine-Related Alarms

HMI Interface Functions:

CS.28: Transmit Data to HMI for Display

CS.29: Save all Operational Data

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.

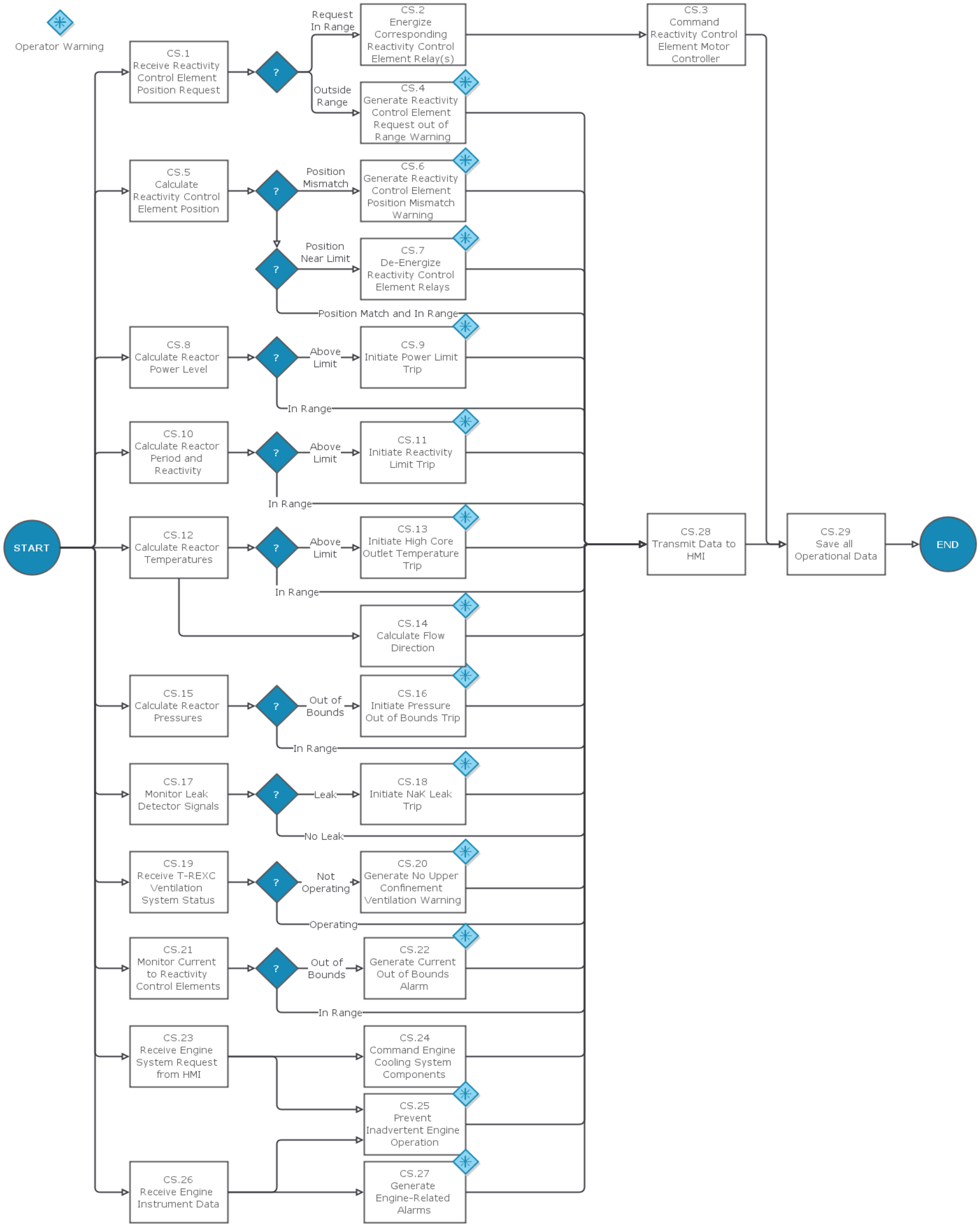

Figure 2. Control System Functional Diagram.

2.1.3 RPS System Functions

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

RPS.1: Receive Seismic Detection Signal

RPS.2: Receive Control System Trip Signal

RPS.3: Provide Manual Scram Button

RPS.4: Remove Power to EM Clutch

RPS.5: Remove Power to Electromagnet

RPS.6: Provide Scram Circuit Status to Control System

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

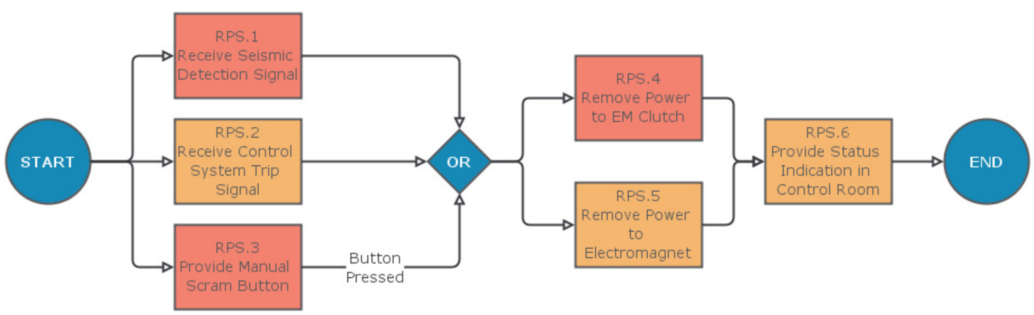

Figure 3. Reactor Protection Subsystem Functional Diagram.

2.1.4 Interlock Functions

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

INT.1: Limit Control Drum or CIA Rod Movement to One at a Time

2.1.5 HMI Functions

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

HMI.1: Receive Reactivity Control Element Position Command from Operator

HMI.2: Receive Engine Cooling System Start/Stop Command from Operator

HMI.3: Receive Engine Power Output Command from Operator

HMI.4: Receive Lead Heating Command from Operator

HMI.5: Receive High Voltage Power Supply On/Off Command from Operator

HMI.6: Transmit Operator Commands to Control System

HMI.7: Receive Signals from Control System

HMI.8: Display Warnings and Alarms to Operator

HMI.9: Annunciate Warnings and Alarms in Control Room

HMI.10: Display Parameters to Operator

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

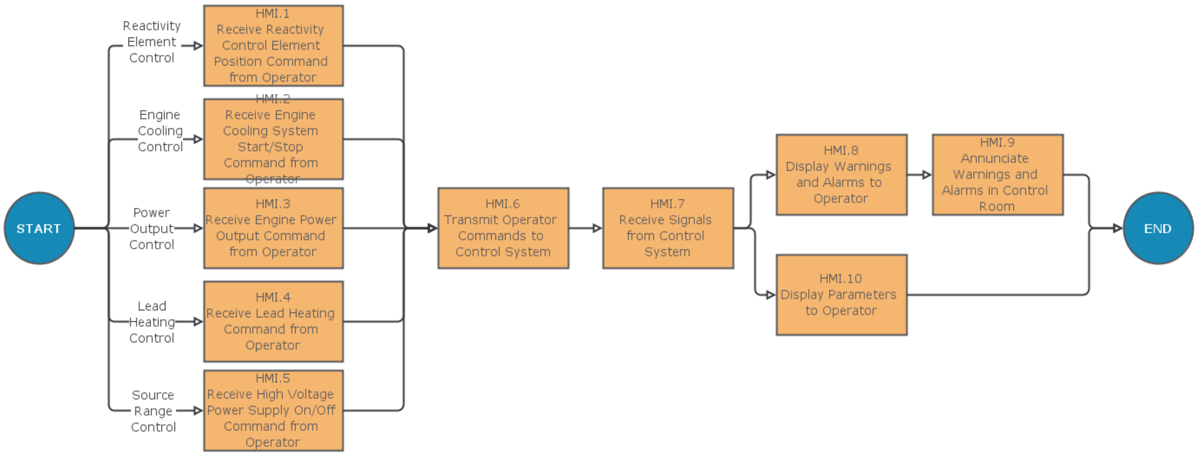

Figure 4. Human Machine Interface Functional Diagram.

2.2 System Classification

The table below provides the classifications of the subsystems of the ICS 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 ICS Subsystem Classifications

Acronym	Subsystem	Classification
RIS	Reactor Instrumentation Subsystem	Safety Related (SR)
CS	Control System	Non-Safety Related - Augment Requirements (NSR-AR)
RPS	Reactor Protection Subsystems	SR
INT	Interlocks	SR
HMI	Human Machine Interface	NSR-AR

2.3 Basic Operational Overview

The following diagram shows the overall system architecture of the ICS and how each of the subsystems (in blue) interface. Grey boxes surrounding the system boundary represent interfacing subsystems not within the scope of the ICS. Orange lines represent electrical interfaces and teal lines represent I&C interfaces. The ICS subsystems are described in more detail in the following subsections.

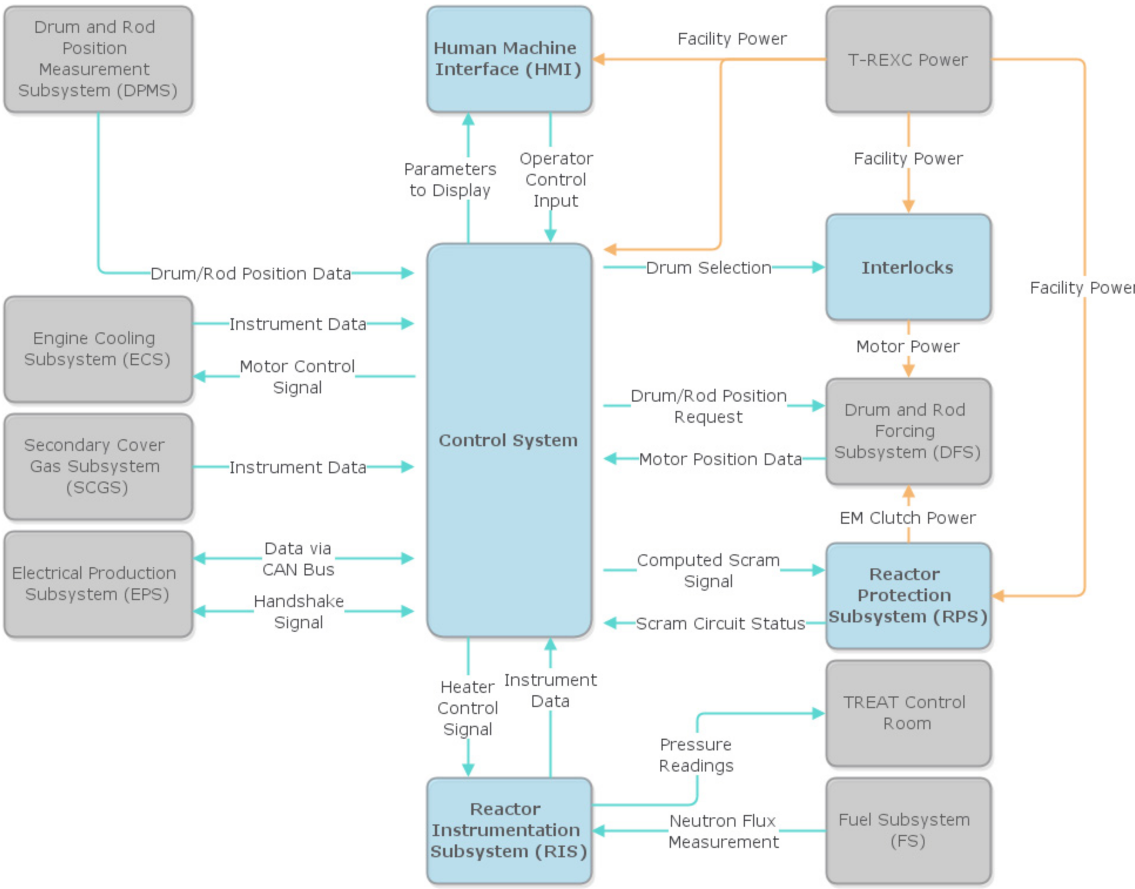

Figure 5. Instrumentation and Control System Architecture and Interfaces.

2.3.1 RIS Basic Operational Overview

The RIS is responsible for measuring critical operating parameters of the reactor systems including temperature, pressure, the presence of NaK outside the primary coolant boundary, and the neutron count. These measurements are routed to the control system for processing and subsequent action. The RIS also includes heaters that can be controlled by the operator using the HMI to heat the primary coolant prior to initial startup.

2.3.2 Control System Basic Operational Overview

The control system serves as the primary integrator between sensors and motors in the Power Generation System (PGS), sensors and controllers in the Reactivity Control System (RCS), and sensors within reactor systems. The control system accepts parameters from all operating instruments, performs calculation and logic solving, and transmits outputs to various actuators. It also accepts control requests from the operator via the HMI. The control system is responsible for recording and storing all data from the operating campaign.

2.3.3 RPS Basic Operational Overview

The RPS initiates the immediate shutdown of the reactor via a relay circuit. The system accepts signals from either the T-REXC seismic sensors, the manual scram button, or the control system and removes power from the electromagnetic clutches of the control drums and electromagnet of the CIA rod to begin the passive insertion of negative reactivity. The system will also passively trip the reactor in the event of a loss of power.

2.3.4 Interlocks

The interlocks ensure that only one control drum (or CIA rod) can be moved at a time. The system consists of a set of relays that route facility power to the control drum and CIA rod motors. The relays are controlled by signals from the control system based on operator commands using the HMI.

2.3.5 Human Machine Interface

The HMI, located in the TREAT control room, provides the interface for operators to either route control requests to the control system in the TREAT facility or to display system parameters transmitted back from the control system. Using the HMI, an operator can select which control drum to move and to what angle. There are also several on/off or start/stop commands available on the interface. The HMI does not include the two separate safety related indications provided by the RIS (reactor and guard vessel pressures) and the DPMS (reactivity control element limit switches).

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 RIS Functional Requirements

[111551] Power Range Neutron Flux Measurement: The RIS shall be capable of measuring the neutron flux in the power range between the cross-over region with the source range detector and 200kW, with at least one decade of overlap.

Rationale: The reactor neutron flux within the power range of the reactor is used to calculate power, reactivity, and period. These parameters are important for the operators to understand the condition of the reactor, including to confirm safe shutdown. One decade of overlap should be provided with the source range detector so that there is no gap in neutron flux measurement.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: RIS.3

[111552] Source Range Neutron Flux Measurement: The RIS shall be capable of measuring the neutron flux in the startup range between the source level to the cross-over region with the power range detectors, with at least one decade of overlap.

Rationale: The reactor instruments must always have a relative indication of neutrons, even when shutdown. The startup detectors must be able to sense these low flux levels and operate until the cross-over region where the power level detectors can take over.

Derived By: [104520] Instrumentation for Reactor Startup

Linked From: RIS.3

[111553] Core Temperature Differential Measurement: The RIS shall provide the capability of measuring the axial differential temperature across the core region with an uncertainty of 5°C or better.

Rationale: The core differential temperature is an important variable for monitoring the state of the reactor core.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: RIS.4

[111554] IHX Temperature Differential Measurement: The RIS shall provide the capability of measuring the primary coolant differential temperature across the Intermediate Heat Exchanger (IHX) with an uncertainty of 5°C or better.

Rationale: The delta temperature across the heat exchanger is an important characteristic for determining power level and heat transfer between the primary and secondary coolants.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: RIS.4

[111555] Primary Coolant Pressure Measurement: The RIS shall provide the capability to measure the pressure in the primary coolant boundary up to 65psig with a resolution better than 2 psi.

Rationale: The pressure reading in the primary coolant boundary is needed to verify the primary coolant system is not leaking and the difference in pressure between the guard vessel and primary is within the design specifications. The maximum analyzed transient overpressure is 63.25psig, so this provides coverage in excess of that value.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.1

[111556] Guard Vessel Pressure Measurement: The RIS shall provide the capability to measure the guard vessel pressure for anticipated operational and transient conditions with a resolution better than 2 psi.

Rationale: The pressure measurement is needed to verify the guard vessel is not leaking and the difference in pressure between the guard vessel and primary is within the design specifications.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.1

[115094] CIA Rod Sheath Pressure Measurement: The RIS shall provide the capability to measure the CIA rod sheath pressure for anticipated operational and transient conditions with a resolution better than 2 psi.

Rationale: The pressure measurement is needed to verify the NaK is not leaking into the CIA rod sheath and the difference in pressure between the CIA rod and primary is within the design specifications.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.1

[111557] Pressure Display: The RIS shall display primary coolant and guard vessel pressures in the control room.

Rationale: The primary coolant and guard vessel pressure utilize different signal transmission than the control system to HMI connection. The pressure display is not considered part of the HMI.

Derived By: [104517] Operator Communication

Linked From: RIS.2

[111558] LOCA Leak Detection: The RIS shall be capable of detecting whether a leak into the guard vessel has caused the primary coolant level in the reactor vessel to drop beneath the core height.

Rationale: The pressures from the guard vessel and primary are expected to maintain the core covered with coolant if a LOCA occurs. However, additional instrumentation will provide defense in depth and allow operators to determine if the core heat removal function is challenged by a LOCA.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.5

[115061] IHX Leak Detection: The RIS shall be capable of detecting a leak between the liner and the IHX (NaK or Secondary coolant leak).

Rationale: The IHX forms the primary coolant boundary and between the IHX and liner is the leak path.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.7

[111559] NaK Leak into Guard Vessel Detection: The RIS shall be capable of detecting small NaK leaks from the primary coolant boundary that have collected in the bottom of the guard vessel.

Rationale: The lowest level will allow the sensors to trigger on any leak from the primary coolant boundary to the guard vessel with minimal coolant loss before sensing the leak.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.5

[111560] CIA Rod Tube Leak Detection: The RIS shall be capable of detecting a primary coolant leak into the CIA rod tube.

Rationale: The CIA rod tube forms part of the primary coolant boundary and is a leak path for NaK.

Derived By: [104514] Primary Coolant Leak Detection

Linked From: RIS.6

[111561] Primary Coolant Heating: The RIS shall be capable of heating the primary coolant.

Rationale: Pre-heating of the primary coolant is desired to speedup operations and physics testing.

Derived By: [104520] Instrumentation for Reactor Startup, [104786] Instrumentation and Control Maintenance and Replacement

Linked From: RIS.9, RIS.10

[111562] Secondary Coolant Temperature Measurement: The RIS shall be capable of measuring the temperature of the secondary coolant with an uncertainty of 5°C or better.

Rationale: The temperature of the secondary coolant will be used to determine the heat transfer between systems and to correlate corrosion estimations.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: RIS.8

3.4.1.2 Control System Functional Requirements

[111564] Power Level Calculation: The control system shall be capable of calculating the reactor power level from the neutron flux signals.

Rationale: Determining the reactor power level is important for safe startup, operation, and shutdown.

Derived By: [104520] Instrumentation for Reactor Startup, [104521] Reactor Power Level Control

Linked From: CS.8

[111565] Power Level Trip: The control system shall initiate a power limit trip upon a calculated reactor power of 83 kWth.

Rationale: A power trip will shut down the reactor upon detection of a power setpoint being exceeded. This will minimize the magnitude of power excursions. The nominal operating power of the reactor is 85kWth.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.9

[111566] Period/Reactivity Calculation: The control system shall be capable of calculating the reactor period and reactivity using inputs from reactor instrumentation.

Rationale: Reactivity/period are indications of how fast the reactor power is changing and are a fundamental part of the reactor control. The control system needs to translate the sensor reading into human readable values that can be understood by the operator.

Derived By: [104520] Instrumentation for Reactor Startup

Linked From: CS.10

[111567] Power Range Reactivity Trip: The control system shall initiate a trip upon calculated reactivity of 0.35$ beyond critical.

Rationale: A reactivity trip is a defense-in-depth feature to the 0.40$ beyond critical safety limit.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.11

[116010] Startup Reactivity Trip: The control system shall initiate a trip upon calculating a reactivity from a period greater than 35 cents when the reactor power is below 1kW.

Rationale: This reactivity trip prevents inadvertent operations during startup at low power levels.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.11

[111568] Temperature Calculation: The control system shall be capable of calculating the temperature value from all signals provided by the RIS and engine cooling temperature sensors.

Rationale: The signals generated by the sensors will need to be converted to proportional values for downstream calculation (e.g., calorimetry) and logic solving.

Derived By: [104517] Operator Communication

Linked From: CS.12

[111569] High Core Outlet Temperature Trip: The control system shall initiate a shutdown upon exceeding a core outlet temperature of 530°C.

Rationale: Excessive heat in the core could challenge the fuel design limits. The control computer is being used as DID to set conservative limits and the software will scram the reactor before the operating limit is reached. A temperature of 532°C is the assumed bulk coolant temperature limit during all normal and anticipated events per ECAR-6332, Rev. 0. The measurement uncertainty margin of 5°C is subtracted to derive the setpoint.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.13

[111570] Primary Coolant Boundary Pressure Trip: The control system shall initiate a trip upon detection of a primary coolant boundary pressure above or below the calculated allowable pressure band for the given reactor temperature.

Rationale: A low primary coolant pressure could indicate a primary coolant leak. A high primary coolant pressure could indicate overfill of coolant or an incorrect temperature reading. A high or low value could also indicate a faulty pressure sensor. The pressure is dependent on the given reactor temperature and must be correlated to the values in ECAR-6586.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.16

[111571] Guard Vessel Pressure Trip: The control system shall initiate a trip upon detection of a guard vessel pressure ±2.5 psig above or below the calculated pressure for the given guard vessel temperature.

Rationale: High and low guard vessel pressures indicate a leak in the guard vessel, a leak in the primary vessel or a faulty pressure sensor. The pressure is dependent on the given guard vessel temperature and must be correlated to this value. The values of this requirement are pending the results of the pressure analysis ECAR-6586.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.16

[115095] CIA Rod Pressure Trip: The Control System shall initiate a trip upon detection of a CIA rod sheath pressure ±2.5 psig above or below the calculated pressure for the given reactor temperature.

Rationale: High and low CIA rod sheath pressures indicate a leak in the primary vessel or a faulty pressure sensor. The pressure is dependent on the temperature and must be correlated to this value. The values of this requirement are pending the results of the pressure analysis ECAR-6586.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.16

[111572] NaK Leak Trip: The control system shall initiate a trip upon receipt of two or more leak signals.

Rationale: The reactor cannot continue to operate following a leak from the primary coolant into the guard vessel. More than one sensor should be indicating that a leak has occurred. If there is only one sensor then the sensor may be faulty. A majority of the leak detectors are at the lowest point in the guard vessel. Another set of leak detectors is placed just above the core. These leak detectors confirm the NaK is still above the core after a leak. Additional leak detectors are in the CIA housing and next to the liner in the secondary coolant.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.18

[115382] T-REXC Ventilation Warning: The Control System shall warn operators prior to reactor start-up if the T-REXC ventilation system is not operating.

Rationale: Operating UCS ventilation is a prerequisite for reactor operation.

Derived By: [104517] Operator Communication

Linked From: CS.19, CS.20

[115381] T-REXC Ventilation Stop Warning: The Control System shall warn operators if the reactor is operating and the TREX-C ventilation system is not operating.

Rationale: Operating UCS ventilation is a prerequisite for reactor operation.

Derived By: [104517] Operator Communication

Linked From: CS.19, CS.20

[111573] Control Drum and CIA Rod Selection: The control system shall provide the control signal to actuate the appropriate interlock relay based on the reactivity control element selection received from the operator via the HMI.

Rationale: The relays prevent actuation of more than one reactivity control element at a time but must be actuated by signals routed through the control system.

Derived By: [104521] Reactor Power Level Control, [104523] Reactor Shutdown

Linked From: CS.2

[111574] Control Drum and CIA Rod Motor Controller Signals: The control system shall provide the control signal to the DFS motor controllers to move the selected control drum or the CIA rod to the position requested by the operator while validating that the position is within the required bounds.

Rationale: The control system is responsible for providing the link between the operator request on the HMI and the RCS actuators. The control system must first check that the new position requested by the operator is allowable.

Derived By: [104521] Reactor Power Level Control, [104515] System Control for Normal Operating Conditions, [104523] Reactor Shutdown

Linked From: CS.3

[111575] Control Drum and CIA Rod Position Computation: The control system shall compute the position of each control drum and the CIA rod based on inputs received from the DPMS.

Rationale: The positions of each control drum and the CIA rod are needed to inform the operator of the status inside the reactor. The control system should translate the sensor to human readable values for eventual display on the HMI.

Derived By: [104523] Reactor Shutdown, [104521] Reactor Power Level Control

Linked From: CS.5

[111576] Control Drum and CIA Rod Position Alarm: The control system shall produce an alarm upon detecting a discrepancy of more than 0.2 degrees or inches in relative position indication from the DPMS (absolute position indicator) and DFS (motor resolver).

Rationale: This defense in depth feature of a position miss-match between the motor resolver and the value measured by instruments will mitigate the chances of a rod binding or twisting within the control drum and allows the operators to take appropriate action (manual scram or manual shutdown).

Derived By: [105301] Reactivity Control Element Position Indication

Linked From: CS.6

[111577] EM Clutch Current Monitoring: The control system shall be capable of monitoring the currents to the control drum electromagnetic clutches and the CIA rod electromagnet and generating an alarm if they exceed 0.5 and 0.32 A, respectively, after stabilizing for 2 to 3 seconds.

Rationale: The clutch power should be monitored for system health and as a defense in depth feature for the scram function.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: CS.21, CS.22

[111578] Control Drum and CIA Rod Motor Current Monitoring: The control system shall be capable of monitoring the currents to the control drum or CIA rod motors and generating an alarm if they exceed 1.39 A.

Rationale: All control drum motor current should be monitored for system health.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: CS.22, CS.21

[111579] Flow Direction Determination: The control system shall be capable of calculating the direction of primary coolant flow within the primary coolant loop and warning the operator on an incorrect flow direction condition.

Rationale: The flow direction must be determined to ensure coolant is flowing in the correct direction for heat transfer. Since the system flow is passive, it might be possible for counter-flow.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: CS.14

[111580] Engine Start Interlock: The control system shall prevent the power conversion engines from starting until receiving positive confirmation that the inner coolant loop flow is greater than 20 Lpm and the engine control unit indicates operational readiness via CAN bus.

Rationale: This interlock, referred to as the "handshaking" signal, prevents improper operation of the engine and reduces the potential for equipment damage if the engine starts without a heat sink. 30 Lpm is the manufacturer's specification for achieving the minimum differential temperature across the engine. 20 Lpm is selected as an initial lower limit. Once operation has started the level may be lowered.

Derived By: [104519] Power Generation Startup

Linked From: CS.25

[111581] Engine Controller Error Warning: The control system shall generate a warning upon encountering an unanticipated error from the engine controller.

Rationale: An error in an engine or engine cooling loop presents an unknown state and requires operator acknowledgement and subsequent action.

Derived By: [104517] Operator Communication

Linked From: CS.27

[116015] Engine Communication Warning: The control system shall generate a warning if an engine control unit has not responded within 5 seconds of a heartbeat signal.

Rationale: The control system periodically checks the communication with the engine control units. If the units are unresponsive, the operators should be warned of a potential equipment failure.

Derived By: [104519] Power Generation Startup, [104522] Power Generation Output Control, [104524] Power Generation Shutdown

Linked From: CS.27

[116016] Loss of Engine Communication Trip: The control system shall warn operators upon loss of communication with an engine control unit greater than 20 seconds.

Rationale: The control system periodically checks the communication with the engine control units. If the units are unresponsive, the operators will be warned of a potential equipment failure. However, if the operators are not able to respond in time, the reactor should shut down to prevent equipment damage.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: CS.27

[111582] Loss of Flow Warning: The control system shall generate a warning upon detection of a loss of flow in the engine cooling loop.

Rationale: A loss of flow could indicate the failure of a pump or, in conjunction with the level indicator, an engine cooling loop leak.

Derived By: [104517] Operator Communication

Linked From: CS.27

[111583] Engine Cooling Motor Control: The control system shall be capable of controlling the engine cooling inner loop pump speed, outer loop pump speed, and heat rejection unit fan motor speed.

Rationale: These are the basic controls to move the fluid and remove heat effectively.

Derived By: [104524] Power Generation Shutdown, [104522] Power Generation Output Control, [104515] System Control for Normal Operating Conditions

Linked From: CS.24

[111584] Engine Coolant Temperature Differential Warning: The control system shall generate a warning if the coolant temperature differential across the engine exceeds 10°C.

Rationale: The flow rate of the engine cooling loop must be controlled to maintain the required energy temperature drop across the Stirling engine. A temperature differential greater than 10C may be tolerated for acceptable periods of time during system calibration.

Derived By: [104522] Power Generation Output Control

Linked From: CS.27

[111585] Rate of Engine Coolant Temperature Change Alarm: The control system shall generate an alarm if the rate at which the engine coolant temperature decreases exceeds -15°C/min or if the rate at which the engine coolant temperature increases exceeds 7°C/min.

Rationale: This rate of transient temperature change is specified by the manufacturer to mitigate thermal stress on the engine. Ideally the rate of coolant temperature change is kept within a smaller band.

Derived By: [104519] Power Generation Startup, [104524] Power Generation Shutdown, [104522] Power Generation Output Control

Linked From: CS.27

[111586] Active Engine Cooling Alarm: The control system shall generate an alarm if the secondary coolant temperature is above 150ºC and no engine cooling loop flow is detected.

Rationale: The engine must be actively cooled during reactor operation to prevent damage or to extend the engine life. Heated secondary coolant and subsequent heat transfer into the engine without active engine cooling will overheat the engine.

Derived By: [104519] Power Generation Startup

Linked From: CS.27

[111587] Engine Cooling Loop Level Alarm: The control system shall generate an alarm upon receipt of a low engine cooling loop level.

Rationale: Level detection can be used in conjunction with the cooling loop flow rate and pump speed to infer a leak. Leak detection will warn the operators to take appropriate actions.

Derived By: [104513] Reactor Parameter Monitoring

Linked From: CS.27

[111588] Engine Coolant Temperature Alarm: The control system shall generate an alarm if the coolant for the engine is above 70ºC.

Rationale: The maximum coolant temperature is 80 ºC based on the specification from the manufacturer. Margin should be provided to warn the operator prior to exceeding this operational limit.

Derived By: [104522] Power Generation Output Control

Linked From: CS.27

[116009] Engine Frequency Alarm: The control system shall generate an alarm if the engine frequency drops below 4 Hz below the nominal value.

Rationale: A low engine frequency could possibly indicate that Helium has leaked from the engine.

Derived By: [104517] Operator Communication

Linked From: CS.27

3.4.1.3 RPS Functional Requirements

[111590] Seismic Shutdown Initiation: The RPS shall remove power to the control drum EM clutches and CIA rod electromagnet within 1/2 second of receiving a seismic detection signal from T-REXC.

Rationale: Seismic p-waves precede s-waves. The reactor must be subcritical before the arrival of a s-wave at the site. Chapter 15 of the TREAT SAR states that the time between the p and s-wave is 3.53 seconds, although 3 seconds is used for margin. 1 second is allocated to detection and initiation while 2 seconds are allocated for final actuation (rotation of the control drum to the shutdown position). Within that 1 second, half the time is allotted to the T-REXC accelerometers while the other half is allotted to the RPS for de-energization.

Derived By: [104518] Postulated Accident Scram, [112048] Seismic Trip

Linked From: RPS.1, RPS.4, RPS.5

[111591] Manual Scram Initiation: The RPS shall remove power to the control drum EM clutches and CIA rod electromagnet upon actuation of any of the manual scram buttons by the operator.

Rationale: The manual scram capability ensures that the reactor can be shut down at any time by an operator.

Derived By: [104518] Postulated Accident Scram

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

[111592] Automatic Shutdown Actuation: The RPS shall remove power to the control drum EM clutches and CIA rod electromagnet upon receipt of a computed trip signal from the control system.

Rationale: De-energizing the scram circuit allows the spring to move the drums to the shutdown position in the event of a computed shutdown. The control system computed trips are a defense in depth feature to the SR seismic and manual scram capabilities.

Derived By: [104516] Automatic Reactor Shutdown

Linked From: RPS.2, RPS.4, RPS.5

3.4.1.4 Interlocks Functional Requirements

[111593] Control Drum/CIA Rod Movement Interlock: The interlocks shall physically limit the control drum or CIA rod movement to at most one element at a time.

Rationale: Allowing only one drum or rod to be selected and subsequently repositioned mitigates the possibility of abnormal transients.

Derived By: [104521] Reactor Power Level Control, [105300] Reactivity Change Control

Linked From: INT.1

3.4.1.5 HMI Functional Requirements

[111594] Control Drum / Rod Position Selection: The HMI shall enable the operator to select the desired position of individual control drums and the CIA rod.

Rationale: The ability to select the desired position of individual control drums /rod enables manual startup, control, and shutdown. Forcing the selection allows the software to perform a redundant role of forcing only one actuator to move at a time like the interlock circuit.

Derived By: [104523] Reactor Shutdown, [104521] Reactor Power Level Control

Linked From: HMI.1

[116011] Reactivity Control Element Speed Toggle: The HMI shall include the ability to toggle the control drums and CIA rod between the fast and slow speed setting.

Rationale: The reactivity control elements have two settings for speed depending on the operating mode that should be selectable on the operator interface.

Derived By: [104521] Reactor Power Level Control

Linked From: HMI.1

[116012] Reactivity Control Element Selection Display: The HMI shall clearly display which reactivity control element has been selected by the operator.

Rationale: The HMI should visually confirm the selection by the operator before the position is chosen.

Derived By: [104521] Reactor Power Level Control

Linked From: HMI.10

[111595] Control Drum and Rod Position Display: The HMI shall display the continuous position of each control drum and the CIA rod in the control room.

Rationale: Drum and rod movement are the only control function for the reactor operation and the position display provides a confirmation that the commanded position was obtained. The drum and rod positions also allows the operator to verify shutdown status of the reactor without relying on nuclear instrumentation.

Derived By: [104517] Operator Communication

Linked From: HMI.10

[111596] Engine Cooling Start and Stop: The HMI shall enable the operator to turn on and off the engine cooling system motive components.

Rationale: The operator should have control over the startup and shutdown of the enigne coolant loops.

Derived By: [104524] Power Generation Shutdown, [104519] Power Generation Startup

Linked From: HMI.2

[111597] Source Range Power Supply Control: The HMI shall include the ability to turn the high voltage power supply to the source range detectors on and off.

Rationale: The startup detectors must be turned OFF when exceeding their applicable operational range to avoid continual saturation of the detector and prevent damage to it.

Derived By: [104520] Instrumentation for Reactor Startup

Linked From: HMI.5

[111598] Heater Control: The HMI shall include the ability to turn the primary coolant heaters on and off and to set their temperature setpoint.

Rationale: The heaters can to be turned on and off to assist in startups and initial reactor physics testing.

Derived By: [104520] Instrumentation for Reactor Startup

Linked From: HMI.4

[111599] Important Parameters for Display: The HMI shall display the continuous values of the following parameters, at minimum, based on input from the control system:

- Neutron detector levels
- Reactor power level
- Reactor period / reactivity
- Reactor core temperatures
- IHX temperatures
- Leak detector status
- Engine cooling loop temperature and flow
- Engine cooling loop pump and HRU motor speeds
- Indoor and outdoor temperatures
- Stirling Engine health.

Rationale: These parameters are necessary for proper operation of the integrated system. This requirement only sets the minimum parameters to display.

Derived By: [104517] Operator Communication

Linked From: HMI.10

[111600] Warning and Alarm Display and Annunciation: The HMI shall display and annunciate all warnings and alarms generated by the control system.

Rationale: Operations should be made aware of all generated computer alarms.

Derived By: [104517] Operator Communication

Linked From: HMI.8, HMI.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

[111602] RPS Existing Infrastructure Use: The RPS signals between the scram circuit in reactor building (MFC-720) and the manual scram button in the control room (MFC-724) shall use existing TREAT infrastructure.

Rationale: Using existing infrastructure eliminates the cost, effort, and schedule necessary to establish new signal transmission capabilities.

Derived By: [104518] Postulated Accident Scram

[111603] RIS Existing Infrastructure Use: The RIS signals between the pressure transducers in the reactor building (MFC-720) and the analog meter in the control room (MFC-724) shall use existing TREAT infrastructure.

Rationale: Using existing infrastructure eliminates the cost, effort, and schedule necessary to establish new signal transmission capabilities.

Derived By: [104517] Operator Communication

[111604] Control System Existing Infrastructure Use: The control system shall be capable of tying-in to the existing fiber optic network between the reactor building (MFC-720) and the control room (MFC-724).

Rationale: This will maximize the use of existing infrastructure and minimize cost, effort, and schedule to establish new capabilities. The control system will communicate with the HMI via existing fiber optics.

Derived By: [104517] Operator Communication

[111605] HMI Existing Infrastructure Use: The HMI shall be capable of tying-in to the existing fiber optic network between the reactor building (MFC-720) and the control room (MFC-724).

Rationale: This will maximize the use of existing infrastructure and minimize cost, effort, and schedule to establish new capabilities. The HMI will communicate with the control system via existing fiber optics.

Derived By: [104517] Operator Communication

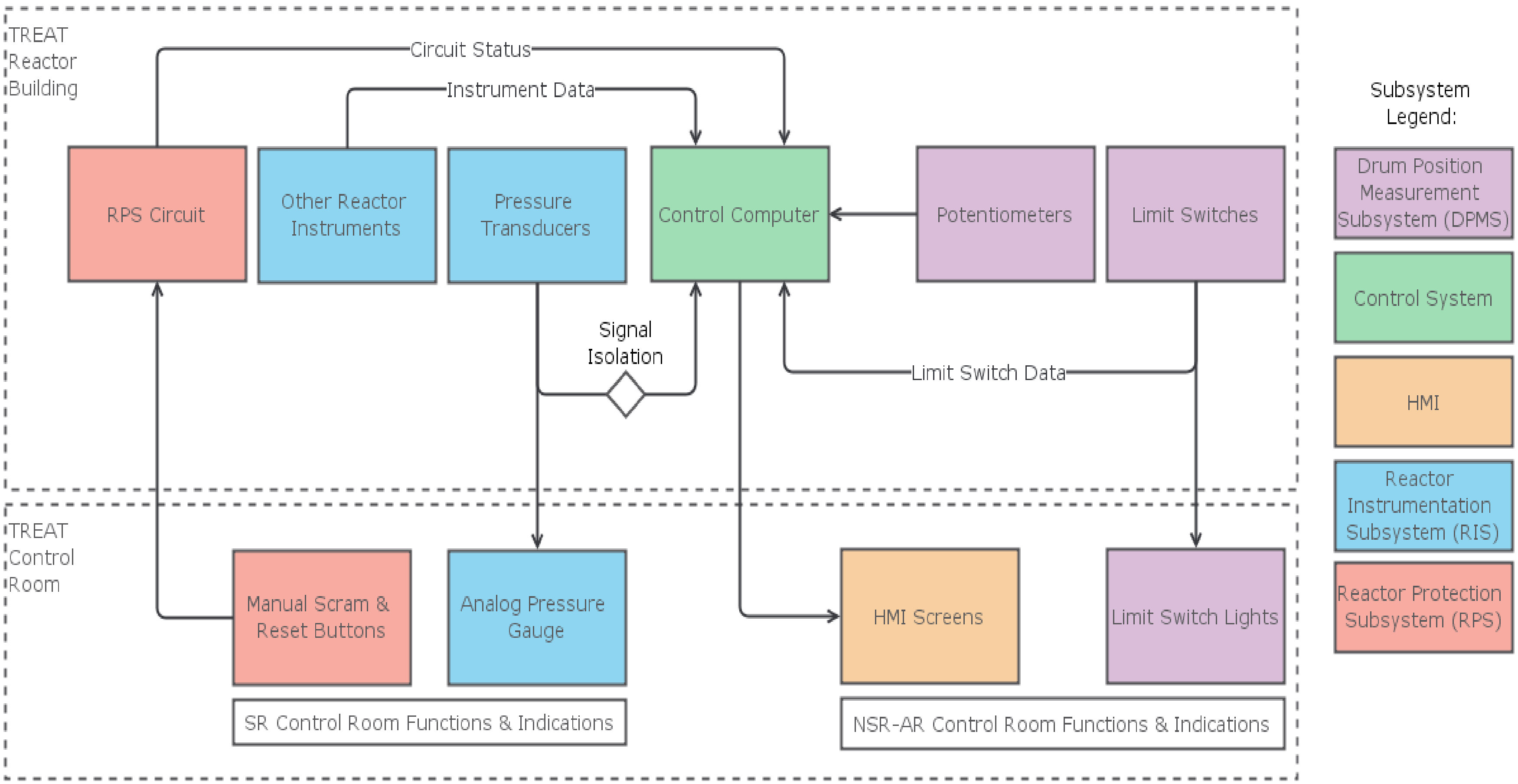

Figure 6. MARVEL Interfaces Associated with Control Room Display.

3.4.4 Code of Record

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

[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

[112308] IEEE-603, "IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations," 2018 Edition.

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

[112295] UL-508A, "Standard for Industrial Control Panels," 2018 Edition.

3.4.5 Operability

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

3.5 Specific Requirements

3.5.1 Radiation and Other Hazards

This section does not apply to this system.

3.5.2 As Low As Reasonably Achievable [ALARA]

This section does not apply to this system.

3.5.3 Nuclear Criticality Safety

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

3.5.4 Industrial Hazards

[111606] Engine Controller Vapor Mitigation: The control system shall provide warning of potential for condensation vapor to form in the engine controller.

Rationale: This prevents water from condensing on the internal electrical components in the engine controller.

Derived By: [104515] System Control for Normal Operating Conditions

3.5.5 Operating Environment and Natural Phenomena

[111607] Temperature Environment for I&C Equipment Within Primary Coolant: The RIS equipment in contact with the primary coolant or within the reactor shall be capable of operating at temperatures between 10°C and 704°C.

Rationale: Equipment must be designed to function in the environment in which it is installed. The bulk coolant temperature is expected to remain below 704 deg C during all postulated accidents.

Derived By: [104525] Instrumentation and Control Design for Operating Environment

[111608] Pressure Transducer Seismic Design Criteria: SR pressure instrumentation components that form part of the primary coolant boundary shall be designed to the seismic criteria of IBC-2015, using the response coefficients in Table 3-1 of DOE-STD-1020.

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

Derived By: [104526] Instrumentation and Control Seismic Design

[111609] Temperature Environment for I&C Equipment Outside T-REXC: All ICS SSCs (Interlocks, Control System, RPS, and HMI) installed outside the T-REXC pit shall be capable of operating at indoor temperatures between 0°C and 32°C.

Rationale: Equipment must be designed to function in the environment in which it is installed. TREAT Facility temperatures are expected to remain between 0 deg C and 32 deg C.

Derived By: [104525] Instrumentation and Control Design for Operating Environment

[111610] Radiation Environment for RIS Components in Guard Vessel: RIS SSCs installed within the guard vessel shall be capable of operating in a radiation exposure in the range of 300MRads.

Rationale: Equipment must be designed to function in the environment in which it is installed. The instrumentation will need to function in a radiation field within the guard vessel / reactor.

Derived By: [104525] Instrumentation and Control Design for Operating Environment

[111611] Neutron Detector Temperature Environment: The neutron detectors shall be able to operate in a temperature range up to 80°C.

Rationale: According to the manufactures specification the neutron detectors have temperature limits at or above 80 deg C.

Derived By: [104525] Instrumentation and Control Design for Operating Environment

3.5.6 Human Interface Requirements

[111612] Control Room Scram Button: The RPS shall provide a manual scram button in the TREAT control room (MFC-724).

Rationale: The manual scram button allows operators the ability to rapidly terminate the fission process at operator's discretion.

Derived By: [104518] Postulated Accident Scram

Linked From: RPS.3

[111613] TREAT Building Scram Button: The RPS shall provide a manual scram button in the TREAT facility (MFC-720) enabling immediate shutdown of the reactor.

Rationale: The TREAT facility is evacuated when the reactor is operational. The local scram button provides additional control for unexpected conditions.

Derived By: [104518] Postulated Accident Scram

Linked From: RPS.3

[111614] Alarm Display: All possible alarms provided by the HMI shall be displayable without the need to scroll or change screens.

Rationale: This ensures alarms cannot be hidden from view of the operators.

Derived By: [104517] Operator Communication

[111615] Alarm Status: The HMI shall display the alarm status and require a positive action to reset or silence an alarm.

Rationale: Requiring positive action for alarms ensures alarms are recognized or not missed.

Derived By: [104517] Operator Communication

[111616] Alarm Importance: The HMI shall display the importance of each alarm (Notification, Out of Tolerance Value, Casualty Condition, etc.).

Rationale: This will aid the operators in determining alarm response especially if more than one alarm occurs at the same time. The alarm should guild the operator to the appropriate response to the alarm.

Derived By: [104517] Operator Communication

[116014] Display Rate: The HMI shall provide a view rate for all displayed parameters or graphs within the range of 0.1 to 10 Hz.

Rationale: This view rate ensures the display refreshes at a reasonable frequency so that the operators have the most up to date information.

Derived By: [104517] Operator Communication

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

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

3.6.2 Mechanical and Materials

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

3.6.3 Chemical and Process

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

3.6.4 Electrical Power

[111617] Non-Standby Power Supply to Scram Circuit: The RPS shall be provided power by a non-standby backed T-REXC power supply.

Rationale: The power source cannot be on a standby supply or have an uninterruptible power supply to ensure the circuit de-energizes and remains de-energized on a loss of power (i.e., fails safe).

Derived By: [104527] Instrumentation and Control Fail Safe State

[111618] UPS to the Control System: An uninterruptible power supply (UPS) shall supply 30 minutes-worth of uninterruptible power to the control system for monitoring after a loss of offsite power.

Rationale: Uninterruptible power is required to maintain the ability to monitor reactor variables following a loss of offsite power. The UPS must carry the load until the TREAT standby power supply kicks on. In the event of an extended loss of power, the UPS needs to supply enough power for the operators to confirm the safe shutdown condition.

Derived By: [104527] Instrumentation and Control Fail Safe State

[111619] UPS to the HMI: A UPS shall supply 30 minutes-worth of uninterruptible power to the HMI for monitoring after a loss of offsite power.

Rationale: Uninterruptible power is required to maintain the ability to monitor reactor variables following a loss of offsite power. The UPS must carry the load until the TREAT standby power supply kicks on. In the event of an extended loss of power, the UPS needs to supply enough power for the operators to confirm the safe shutdown condition.

Derived By: [104527] Instrumentation and Control Fail Safe State

[111620] Standby Power to UPS: The UPSs for the control system and HMI shall be provided power by a standby-backed T-REXC power supply.

Rationale: A standby-backed power supply ensures that the UPS can seamlessly transition over to a new power source when available to prevent the batteries from running out and interrupting the power supply to the connected load.

Derived By: [104527] Instrumentation and Control Fail Safe State

3.6.5 Instrumentation and Control

[111621] Engine Controller Communication: The control system shall be capable of communicating via CAN bus with the engine controller to request all needed commands and receive information from the controller.

Rationale: The engine controller will control the majority of the engine needs. However, operators will be responsible for setting various parameters for operation and receiving indication of error from the controller.

Derived By: [104524] Power Generation Shutdown, [104519] Power Generation Startup

[111589] Data and Alarm Saving and Transfer: The control system shall save all MARVEL data and alarms for transfer to the T-REXC historian.

Rationale: Alarm history and overall data collection provides the ability to analyze MARVEL performance after operation has completed.

Derived By: [104517] Operator Communication

Linked From: CS.29

[116013] Data Sample Rate: The control system shall be capable of measuring and recording up to 10 samples per second throughout the operational life of the reactor.

Rationale: A high sampling rate will provide the best data set for subsequent analysis.

Derived By: [104517] Operator Communication

3.6.6 Computer Hardware and Software

[111622] Analog Hardware for Manual Scram: Analog hardware shall be used to transmit an operator-induced manual scram in the control room to the scram circuit.

Rationale: Qualifying digital systems for SR functions is time consuming and expensive.

Derived By: [104518] Postulated Accident Scram

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

[111624] Neutron Detector Power Calibration: Power range instruments shall be calibrated to thermal reactor power.

Rationale: Calibration of instruments provides confidence that the parameters measured to evaluate power of the reactor is known and is within the allowed operating parameters for power.

Derived By: [104520] Instrumentation for Reactor Startup

[111625] Manual and Seismic Scram Testability: The RPS shall include features to test the manual and seismic scram capabilities.

Rationale: SR systems must include features to facilitate periodic inspection and testing in order to comply with the single failure criterion.

Derived By: [104785] Instrumentation and Control Inspection and Testing

3.7.2 Inspections, Testing and Surveillances

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

3.7.3 Maintenance

[111626] Instrumentation Removal and Replacement Outside T-REXC: ICS equipment located outside T-REXC shall include provisions for removal and replacement.

Rationale: If I&C equipment fails it should be able to be replaced and returned to service.

Derived By: [104786] Instrumentation and Control Maintenance and Replacement

[111627] Pressure Instrument Isolation Valve: Each RIS pressure instrument penetrating the primary coolant boundary shall have a SR isolation valve.

Rationale: The isolation valve facilitates removal and replacement. The valve must be SR because it forms part of the primary coolant boundary.

Derived By: [104786] Instrumentation and 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

Alarm-related requirements are provided in Section 3.4.1.1.

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

[111628] RPS Redundancy: Each SR RPS trip shall include redundant relays.

Rationale: The RPS design must comply with the single failure criterion.

Derived By: [104780] Instrumentation and Control Single Failure Criterion

[111629] RPS Fail State: All SR RPS relays shall be designed to release upon loss of power or loss of signal.

Rationale: This ensures that the RPS fails to the safe state (scram).

Derived By: [104527] Instrumentation and Control Fail Safe State

[111630] SR and NSR Isolation: Signals from SR instrumentation to the control system shall be isolated.

Rationale: The failure of a NSR system cannot impact the ability of a SR system to perform its functions. Communication between these systems is permissible provided the signal is from the SR to the NSR system and the signal is isolated.

Derived By: [104781] Independence from Control System

3.8.5 Quality Assurance

The INL Quality Assurance Program is applicable to all activities affecting quality including design, procurement, fabrication, construction, receiving, installation, inspection, testing, and operation activities. More specifically, construction QA requirements will be specified on Form 540.10C, Subcontractor Requirements Manual (SRM) Applicability - Construction. Fabrication QA requirements for

INL-performed fabrication will be specified on Form 431.55, Fabrication Services Work Request, as well as associated drawings and referenced specifications. Conformance to technical and quality assurance requirements will be verified by in-process inspections during fabrication, construction, and installation activities. Such inspections will be outlined in the applicable specifications, drawings, and procurement documents including the INL forms noted above. Final acceptance of procured and in-house fabricated components will be accomplished as defined by fabrication work control documents (including drawings and instructions) and procurement documents (including statements of work, specifications, and drawings), as applicable. Final acceptance of assembled systems will be verified through acceptance testing.

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.

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

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

Appendix B System Drawings and Lists

See the Affected Documents List in EC-1758 for a full listing of MARVEL I&C drawings.