MARVEL Technology Review: Reactivity Control System (RCS)

Control Drum, Shutdown Rod (Central Insurance Absorber), Reactor Protection System, and Interlocks

October 19, 2022

MARVEL RCS Development Team

Requirements

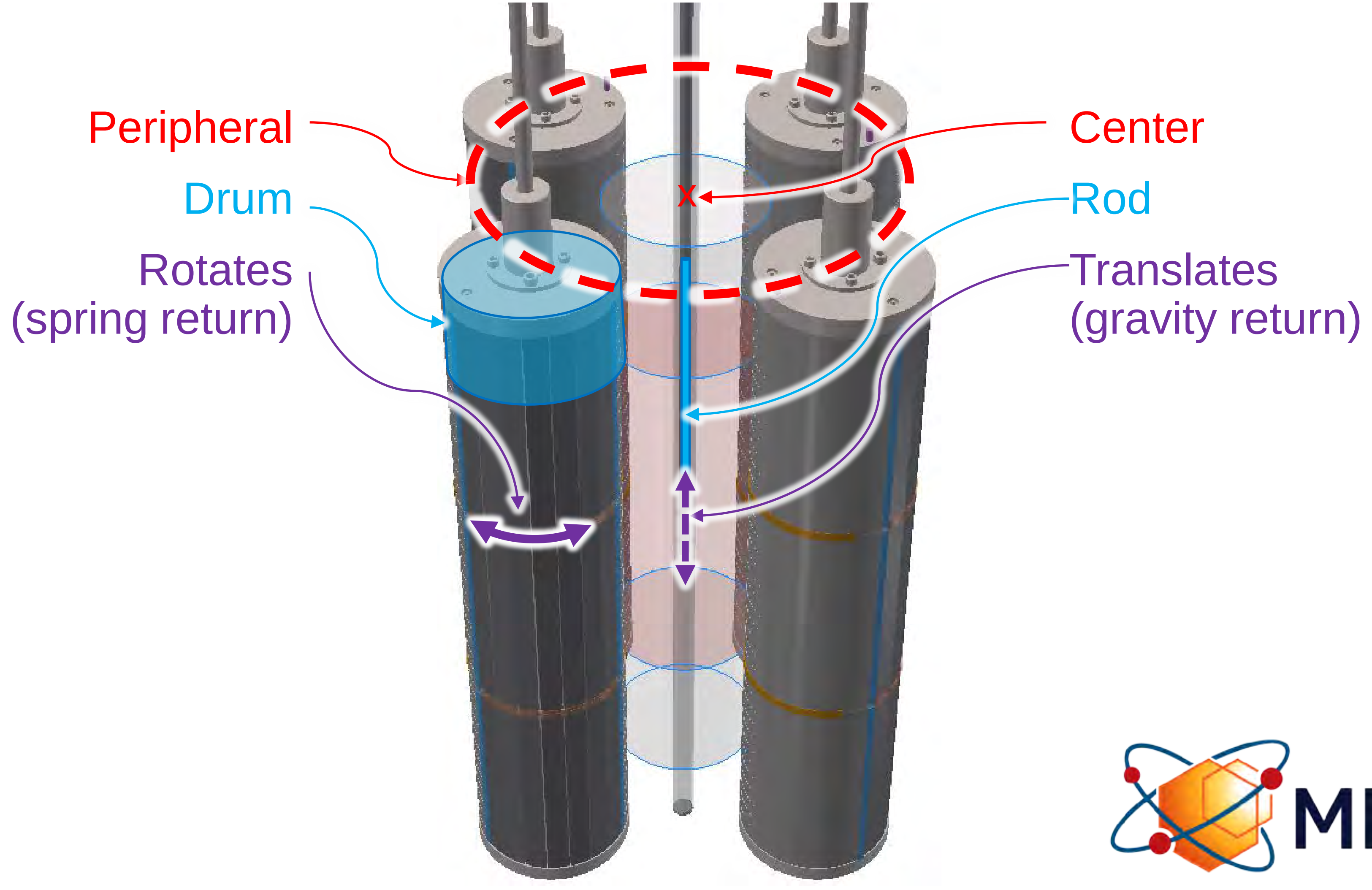
Manual Control	MARVEL reactor shall be brought critical and operated using manual control..
Position Indication	The MARVEL reactor shall have control drum angular position indication over the full range of rotation with resolution to be determined during the design effort.
Safe Shutdown Verification	MARVEL shall be designed with a reactivity control position indication in the control room to verify the reactor is shut down.
Subcritical Fuel Loading	The MARVEL reactivity control system shall have a mechanical locking mechanism conforming to INL lockout-tagout procedure to ensure the reactor stays subcritical during fuel loading. (Safety measures will be in place to prevent going critical).
Seismic Evaluations	MARVEL reactor systems important to safety as identified in the accident analysis as defined in SAR-420 shall be designed to NPH design category 2 (NDC-2).
Reactor Shutdown by Stored Energy	The I&C (RPS) and RCS shall include features to facilitate reactor shutdown on loss of power as achieved by stored energy. May need to revise based on outcome of 'active/passive' discussions.
Seismic Design	MARVEL reactor SSCs important to safety as identified in the accident analysis as defined in SAR-420 Addendum 1 Ch 3 shall be designed to NPH design category 2 (NDC-2).
CIA Operational Limit	The CIA rod shall be operated such that the rod is fully withdrawn before setting of the hard-stops or as part of characterizing the gray rod.
Clutch Health	The control computer shall warn the operator that the current to generate the necessary clutch power is out of tolerance for the expected situation.
Control Drum Maximum Insertion Signal	The drums shall provide a signal when the control drum shaft reaches the reactivity limiting hard-stops.
Drum Position Discrepancy	Upon discrepancy or more than 0.1 degrees in relative position indication from sensors for a single drum, the Control Computer shall provide a means to warn the operators of the discrepancy to take appropriate action (manual scram or manual shutdown).
Motor Overcurrent	Fuses and software induced overcurrent setpoints shall be used to prevent overcurrent to each motor controller or motor.
Motor Replacement	The drum design shall include provisions for removing and replacing failed CD and CIA motors.
CIA Motor and Rod Position Measurement	The CIA rod position measurement components should measure the control rod position with a precision of at least {2} mm
CD Motor and Shaft Position Measurement	The control drums shall measure the motor and shaft position with a precision of at least 0.02 degrees and relay the information to the control computer.
Drum/Rod Measurement Capability	The drum or rod forcing components shall provide the mechanical torque needed to move the control drum or rod in the direction demanded by the motor controller.
Control Drum Shutdown Limit Signal	The Control Drum and CIA Rod shall provide a signal when the control drum or Rod reaches the full shutdown position.
Control Drum Data Transmission	The drums/rod shall transmit the control drum/rod position reading to the control computer.
Manual Reactor Shutdown	The control computer and RCS shall provide the capability to manually shut down the reactor safely in a controlled fashion.
Drum Insertion Speed (RCS)	The RCS shall be capable of achieving a rotational velocity of 0.5 deg/sec for the fast speed setting and 0.05 deg/sec for the slow speed setting.
I&C and RCS Systems Design Life Inside Reactor Vessel	Equipment installed within the reactor shall be designed to operate for at least 2 years without maintenance.
I&C and RCS systems outside reactor vessel	Equipment required for continuous MARVEL operation shall provide at least 99% availability during the two-year operating life of MARVEL, unless specifically noted.
I&C and RCS SSCs within shielding and above the primary boundary	RCS SSCs should be capable of an absorbed neutron dose of [122 -1000 TBD] MRad
Radiation Environment for systems outside of reactor shielding	I&C and RCS SSCs should be capable of operating in a radiation field up to 42mRem/hr.
Design for Operating Environment	The systems shall be designed for the environmental conditions in which it is installed (e.g., thermal, radiation, pressure, vibration).
Control Drum Temperature Environment	The control drum SSCs shall be capable of maintaining their structural integrity at temperatures up to 1100°F.
Control Drum Stress Limits	The Control Drum shall be designed to withstand material stresses (e.g., creep, swelling) imposed by the operating environment and thermal cycles of the reactor.
I&C and RCS Maintenance and Replacement	Accessible system equipment shall include provisions for maintenance and removal/replacement.

MRP Microreactor Program

Final System Description:

- CD and CIA provide significantly diverse methods

Control Drum (CD) *Complemented by* Central Insurance Absorber (CIA)

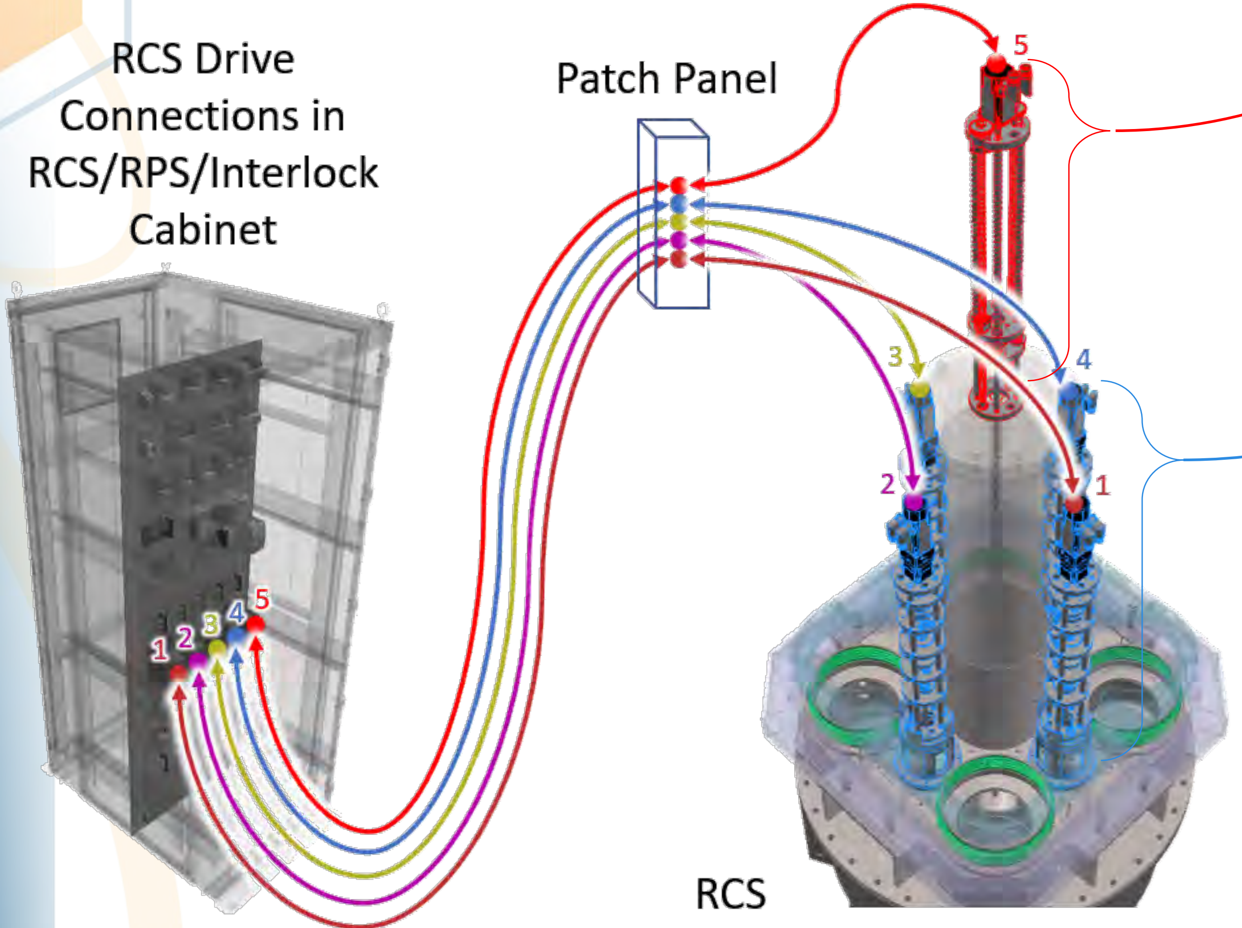


MRP Microreactor Program

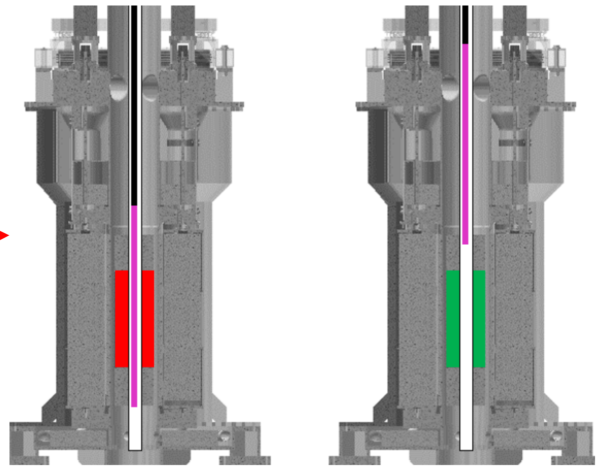
Final System Description: Overview

- Four drums, one absorber, and associated drivers in control cabinet used to control reactor reactivity

RCS Drive Connections in RCS/RPS/Interlock Cabinet

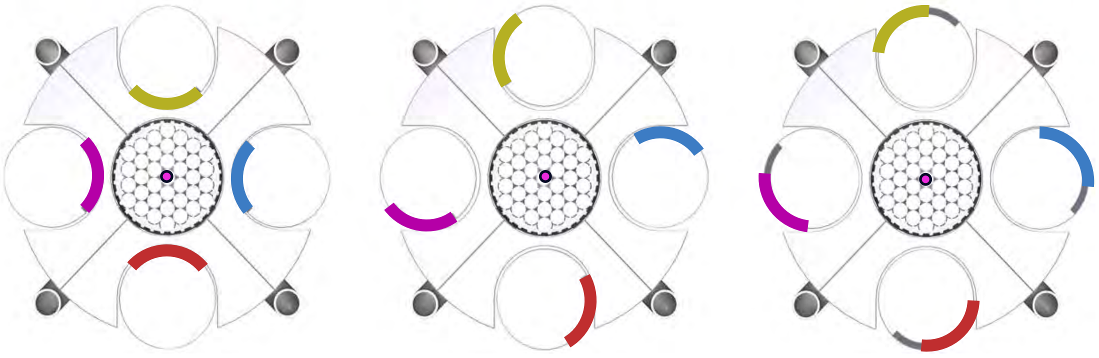


RCS
- 4 CDs (Blue)
- 1 CIA (Red)



CIA In

Criticality Enabled



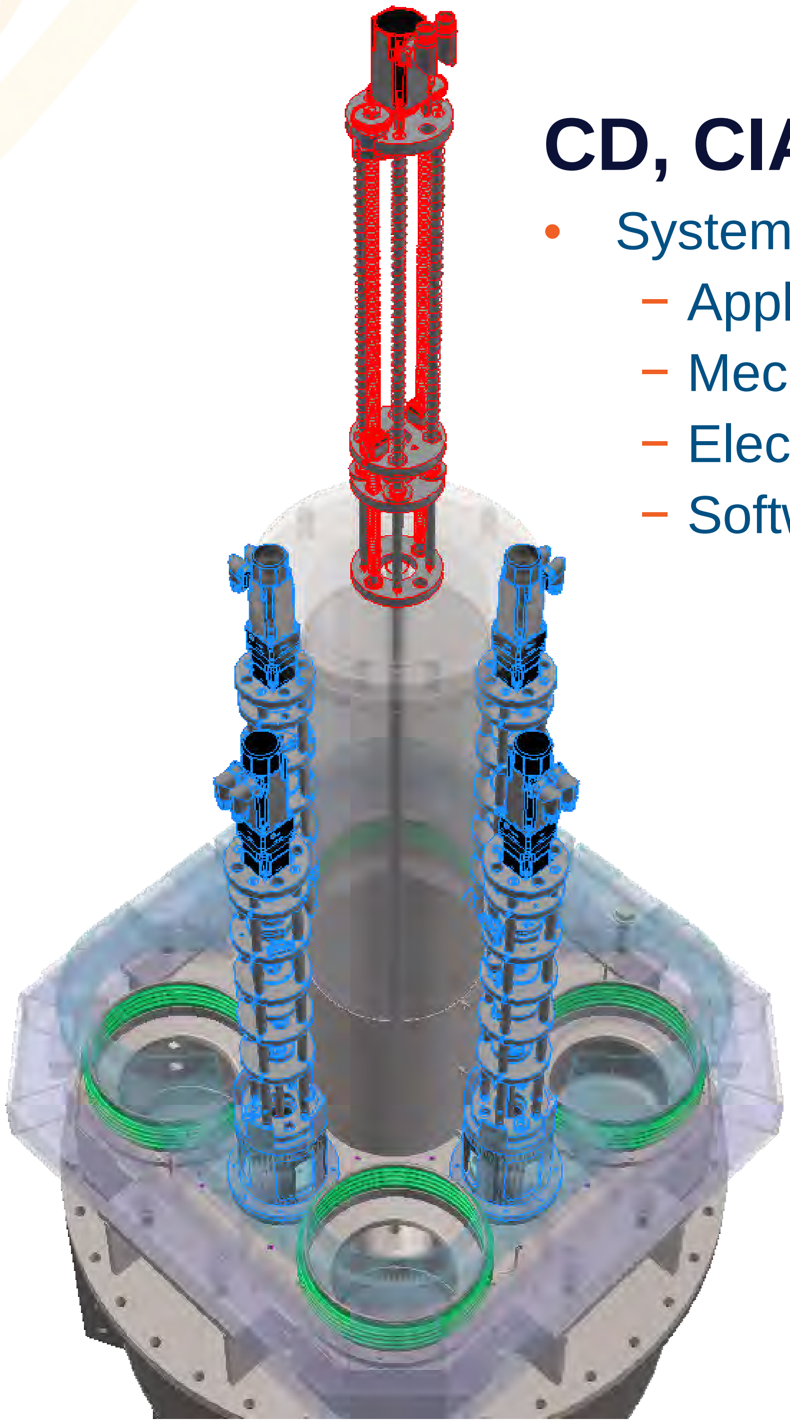
Full-in: Shutdown

Partial Out: Initial Criticality

Full Out: Maximum Reactivity*

*Will be set below full out (180 degree) using a tuned hard stop

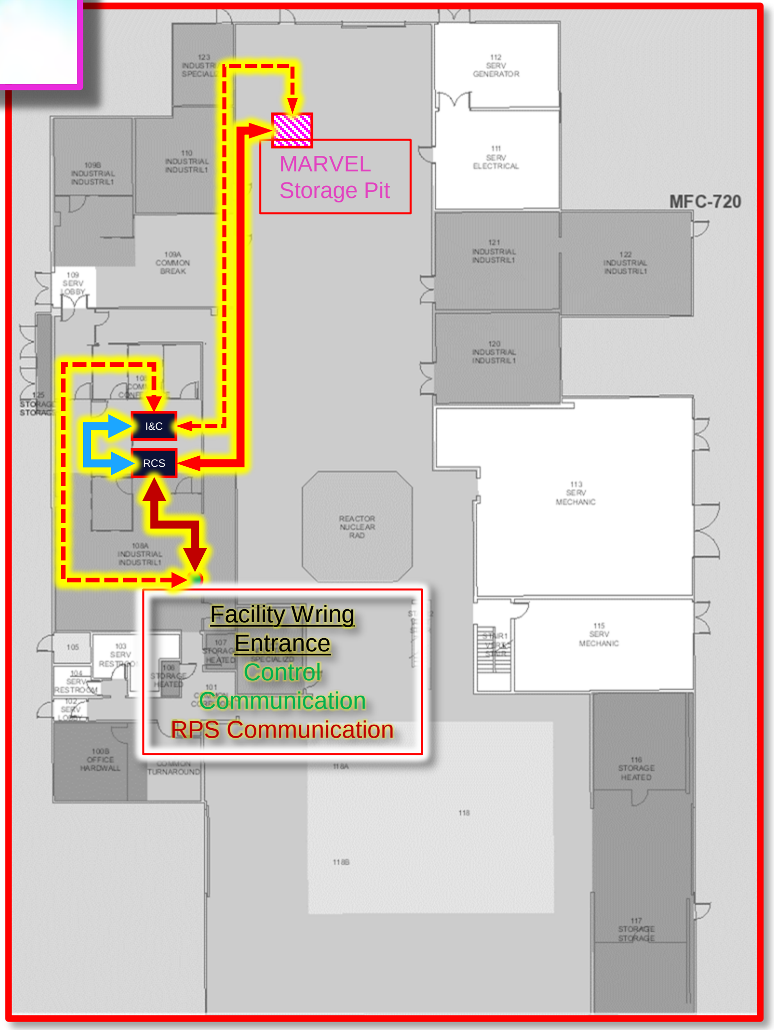
MRP Microreactor Program

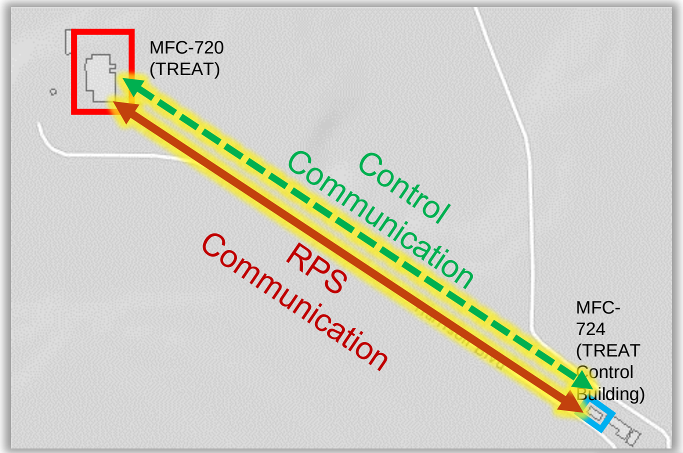


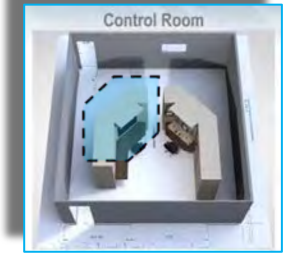
CD, CIA, Interlocks, and RPS Description

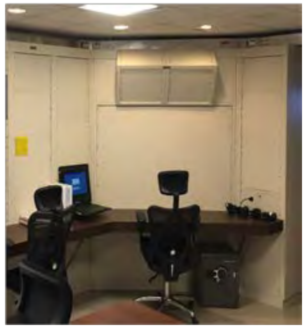
- System categories to be described and related to requirements
  - Application
  - Mechanical
  - Electrical
  - Software

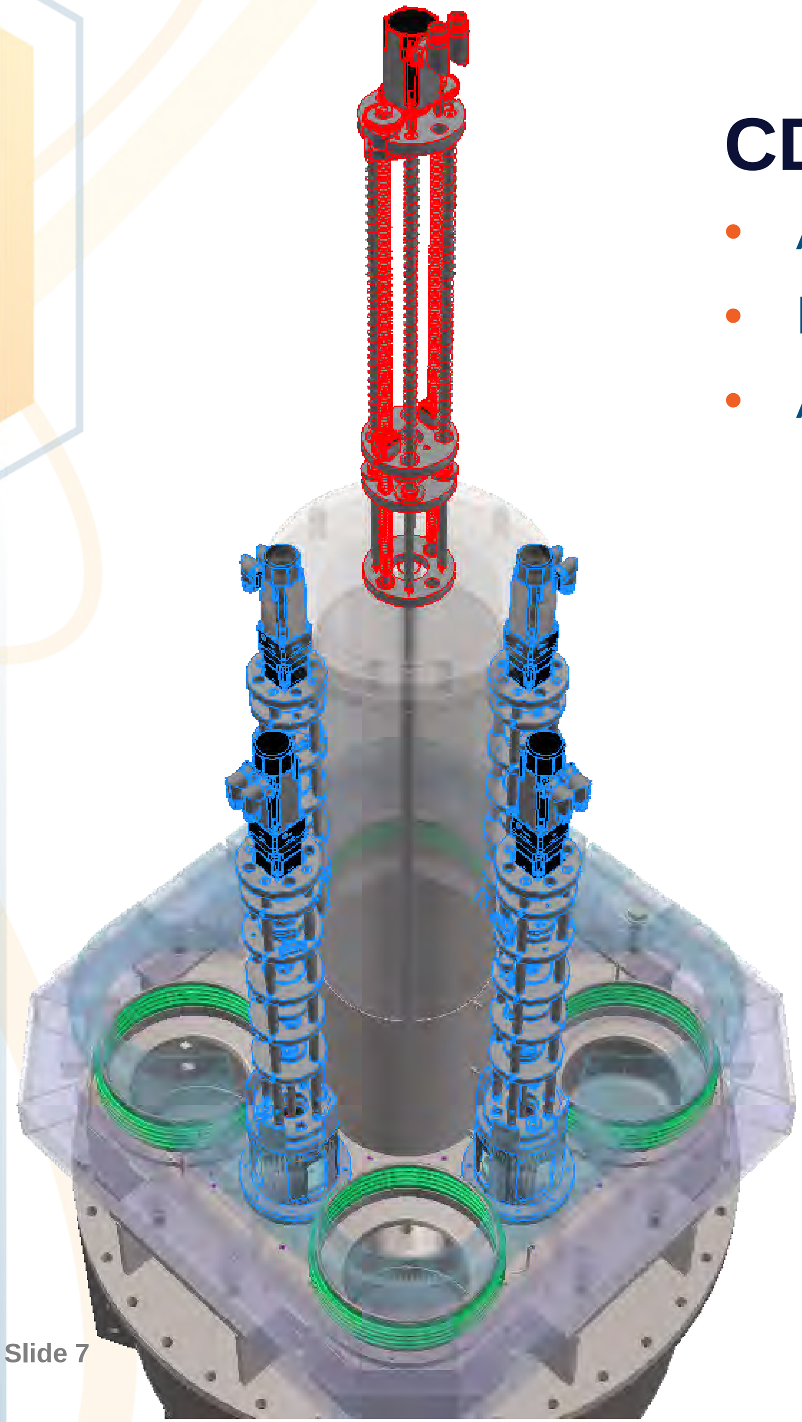
CD, CIA, Interlocks, and RPS Application









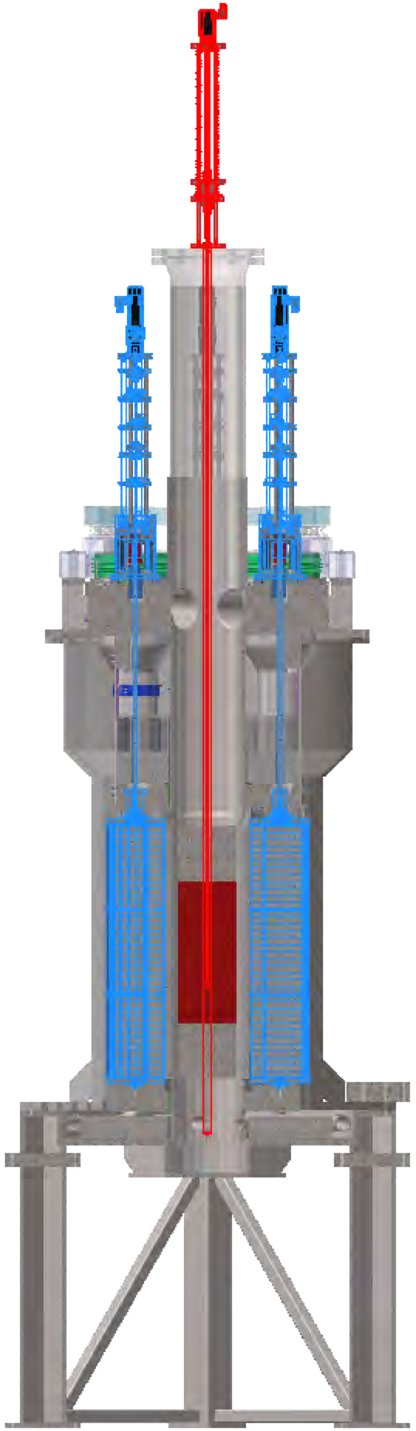


CD and CIA Actuator Application

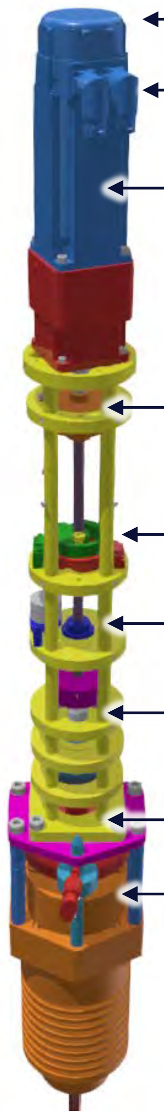
- Actuated at top of reactor
- Penetrations are minimal
- Actuators are accessible

Requirements Satisfied:

- I&C and RCS Maintenance and Replacement
- Motor Replacement



CD and CIA Mechanical



Brake
Drum Insertion Speed

Resolver
CD Motor and Shaft Pos. Measurement
CIA Motor and Rod Pos. Measurement

Motor
Motor Overcurrent
Clutch Health
Manual Control

Gearhead/Ball Screw

Safety Release (Electromagnetic)
Safe Shutdown Verification

Limits
Control Drum Max Insertion Signal
Control Drum Shutdown Limit Signal

Secondary Position
Drum/Rod Measurement Capability
Position Indication
Drum Position Discrepancy

Robust Shutdown
Reactor Shutdown by Stored Energy

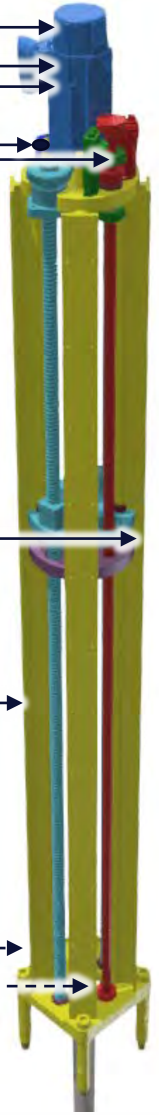
Damping

Lock
Subcritical Fuel Loading

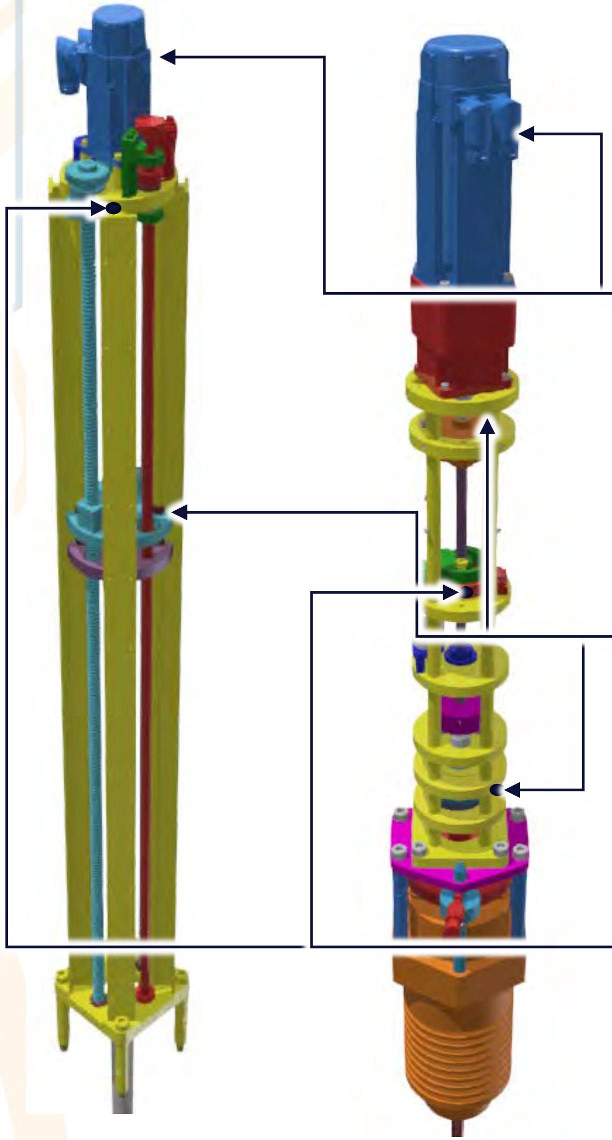
Mathematics

$$J\ddot{\theta} + c_t\dot{\theta} + k_t\theta = T$$

$$m\ddot{x} + c_t\dot{x} + k_t x = F$$



CD and CIA Mechanical to Electrical



CIA and CD System (NSR):

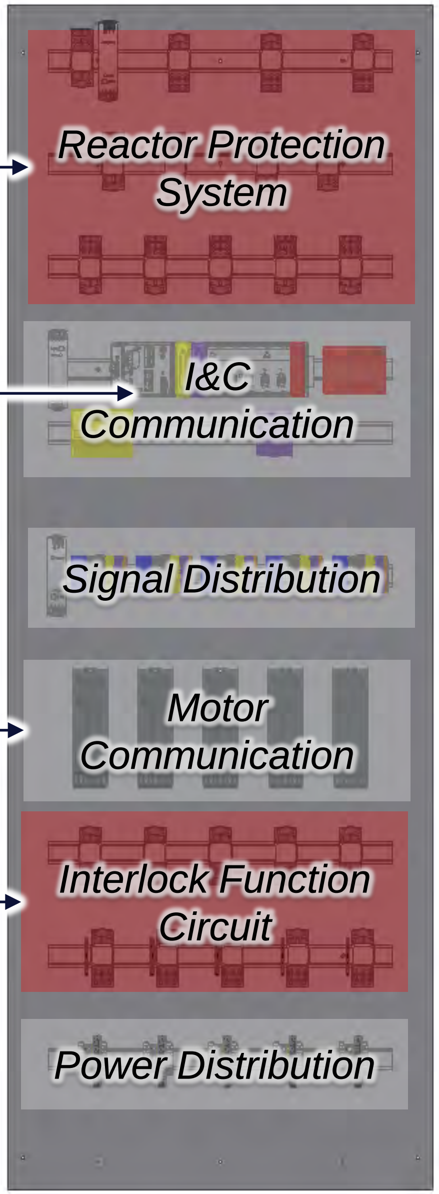
- Read parameters
- Control reactivity via position
- Provided controlled shutdown

Reactor Protection System (SR):

- Stored Energy Shutdown System

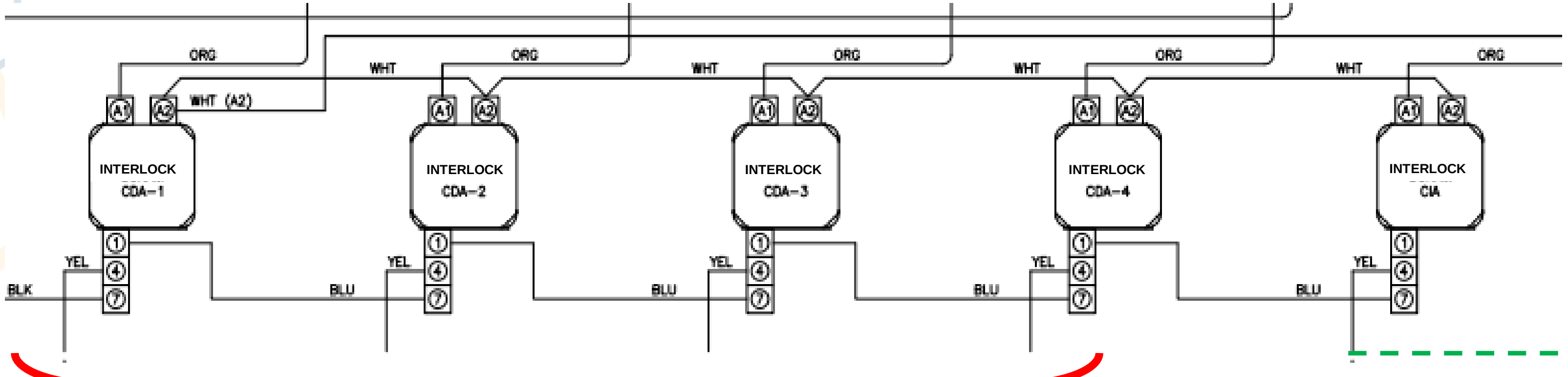
Interlocks (SR):

- Prevent excess reactivity insertion



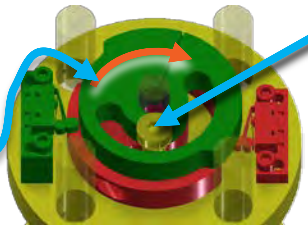
CD System SR Excess Reactivity Insertion Prevention Function

1. Interlock's cascading relay (SR) activates only 1 motor

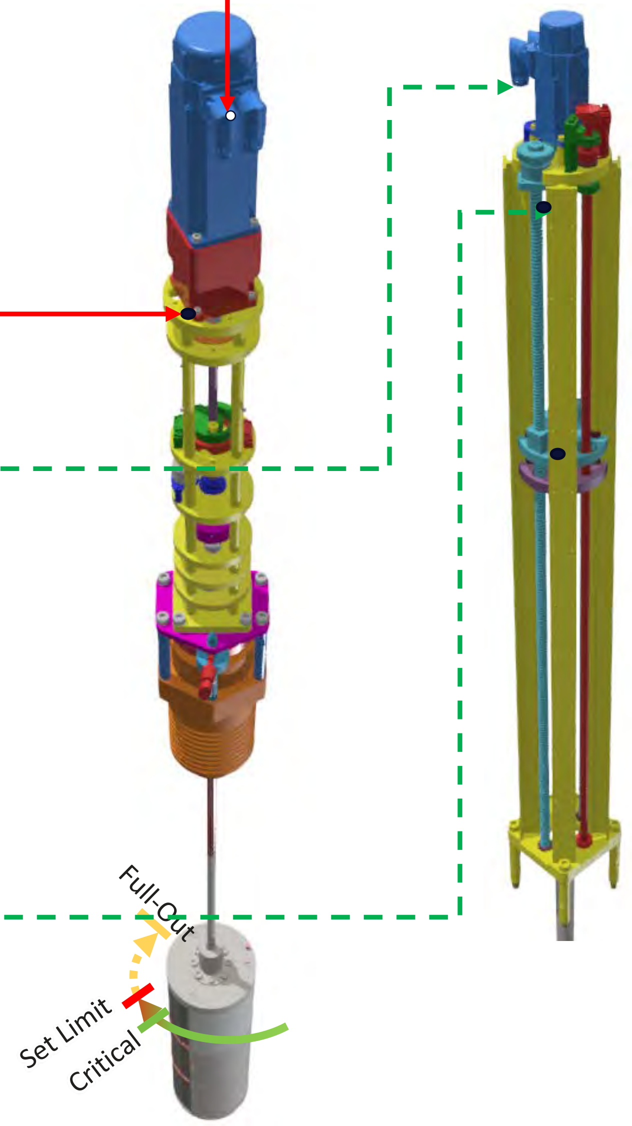


2. Out hard stop prevents drum rotation past limit

Adjustable cam rotation



Bolt stops shaft rotation when it hits end of slot

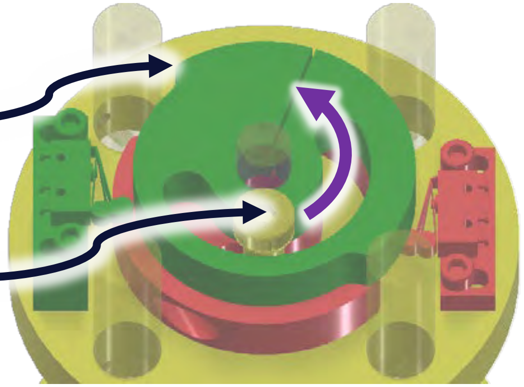


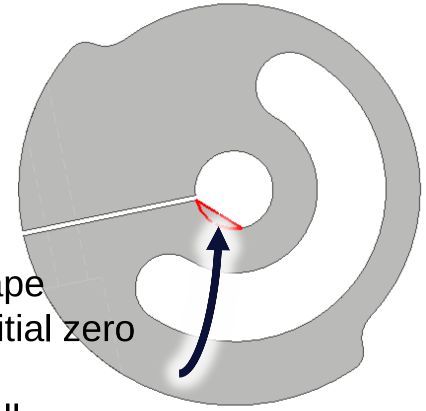
Setting CD and CIA Interlock Hard Stops During Zero Power Physics Testing

- Only adjusted at initial zero power physics test and then fixed

Adjustable cam rotation

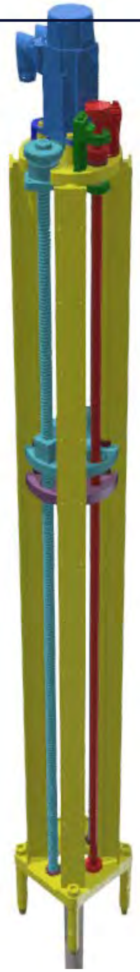
Bolt stops shaft rotation when it hits end of slot





Fab final d-shape feature after initial zero power test
- Direct install
- Or tack weld in shim

- Hard-stops at top and bottom



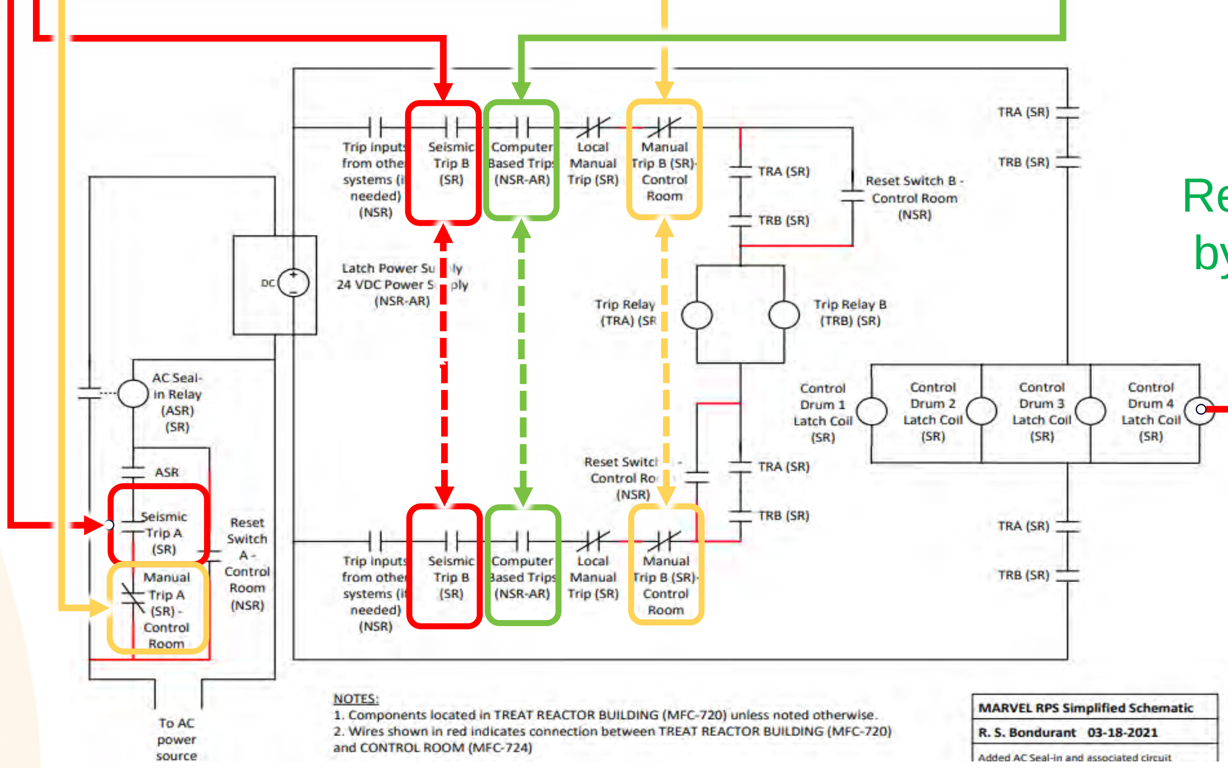
SR Robust Stored Energy Shutdown Function

1. Reminder: Motor can drive drum to shutdown (NSR)
2. RPS releases Clutch (SR) releasing spring (SR)

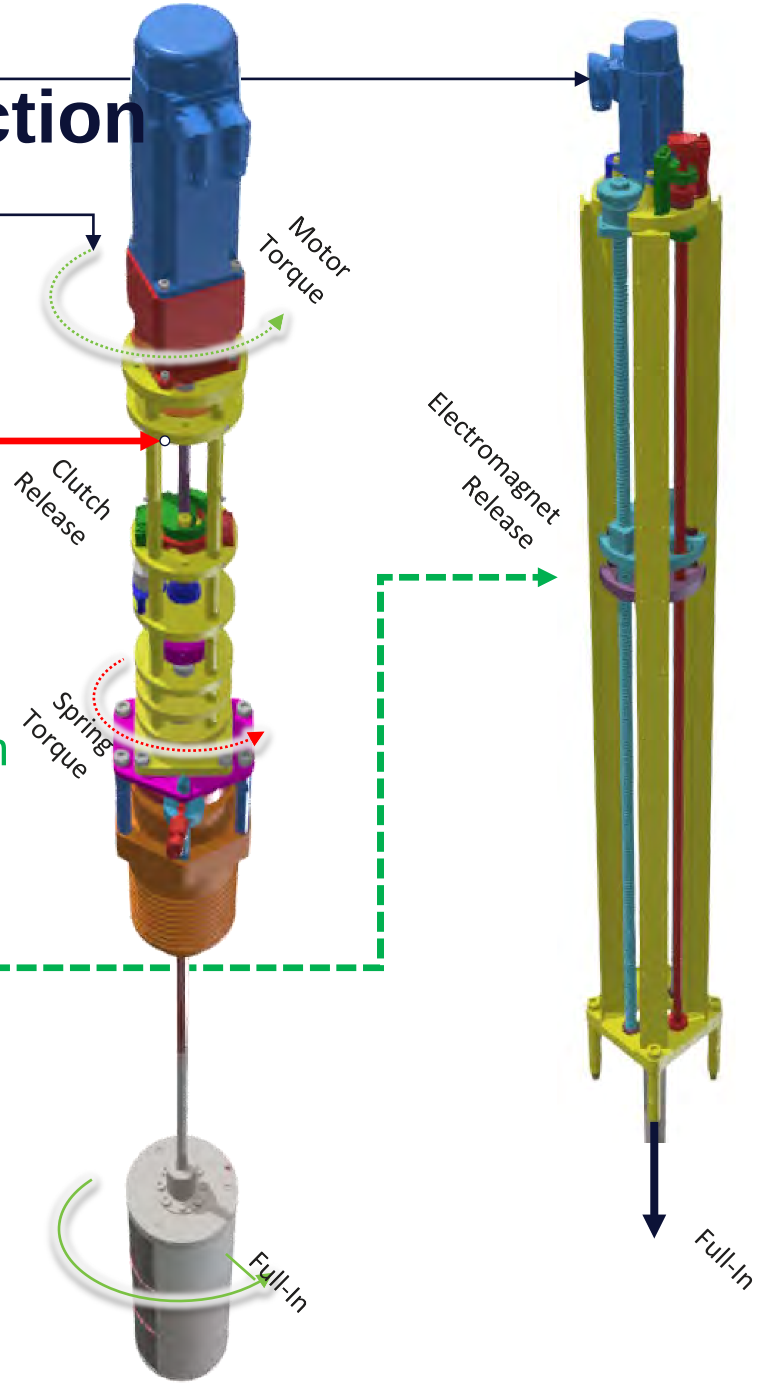
Manual Reactor Shutdown

Seismic and Manual Safety Related (SR)

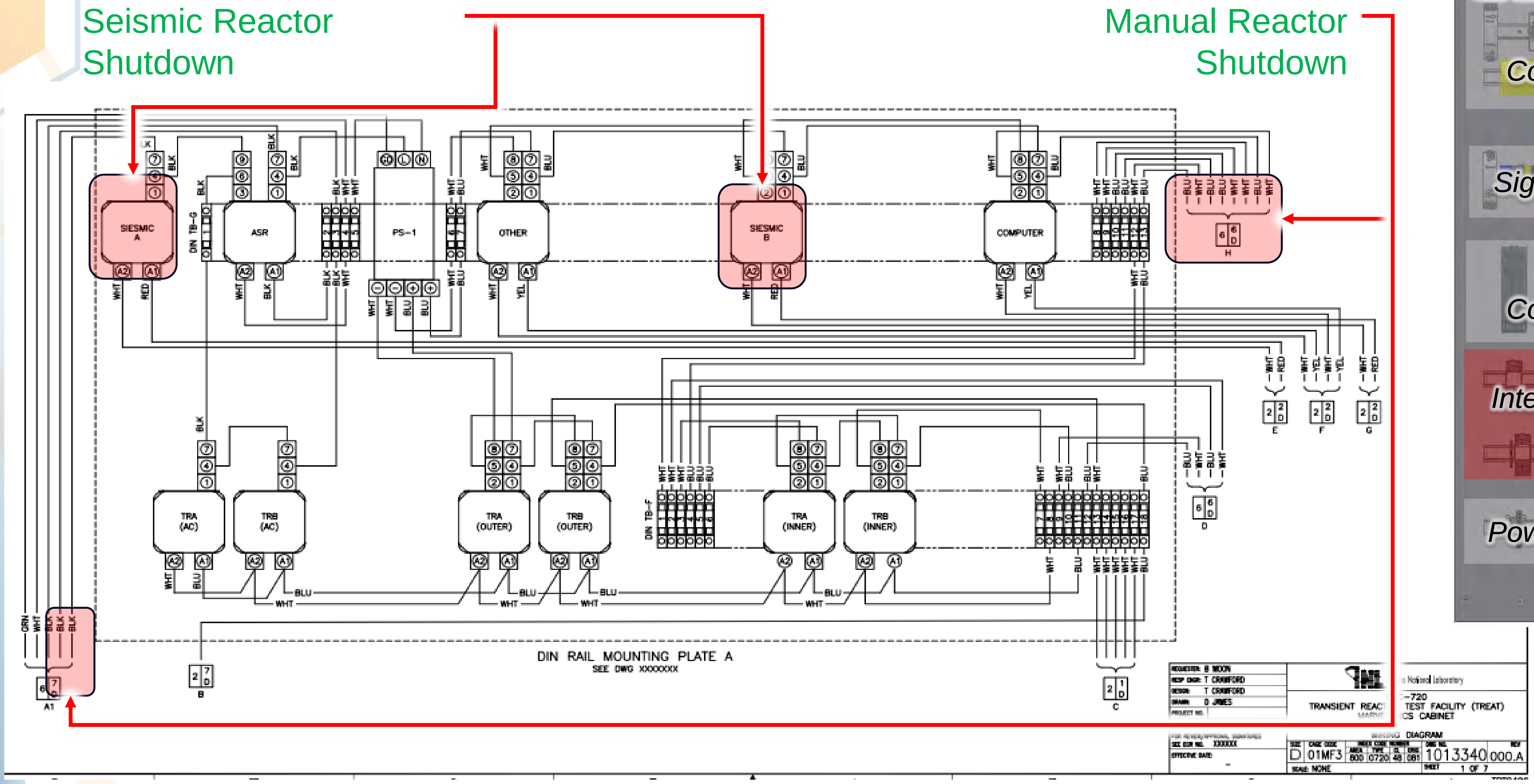
The computer-based trips provide defense-in-depth (NSR)

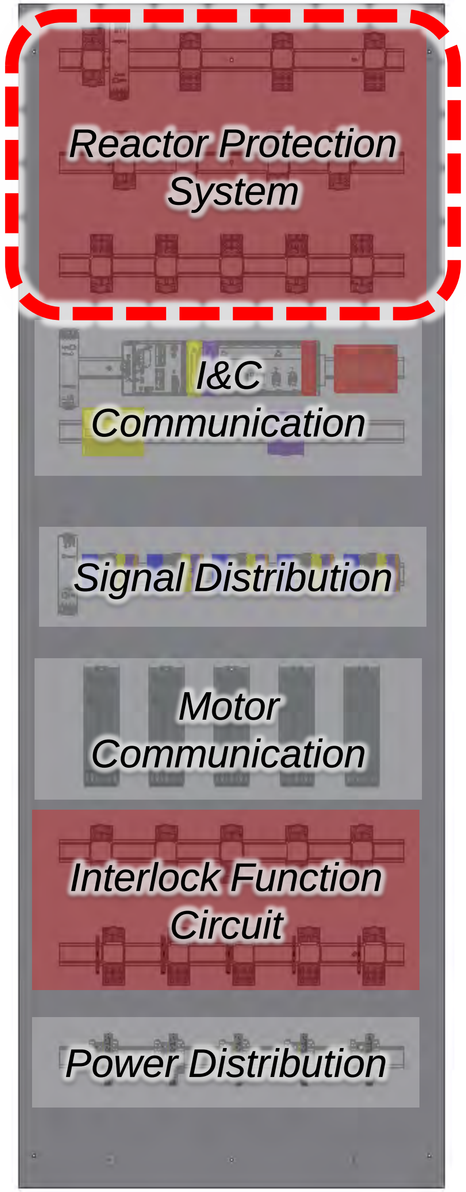


Reactor Shutdown by Stored Energy



RPS Electric Requirements





CD, CIA, and RPS Electric Requirements

Seismic Reactor Shutdown

Manual Reactor Shutdown

Clutch Health

Drum/Rod Measurement Capability

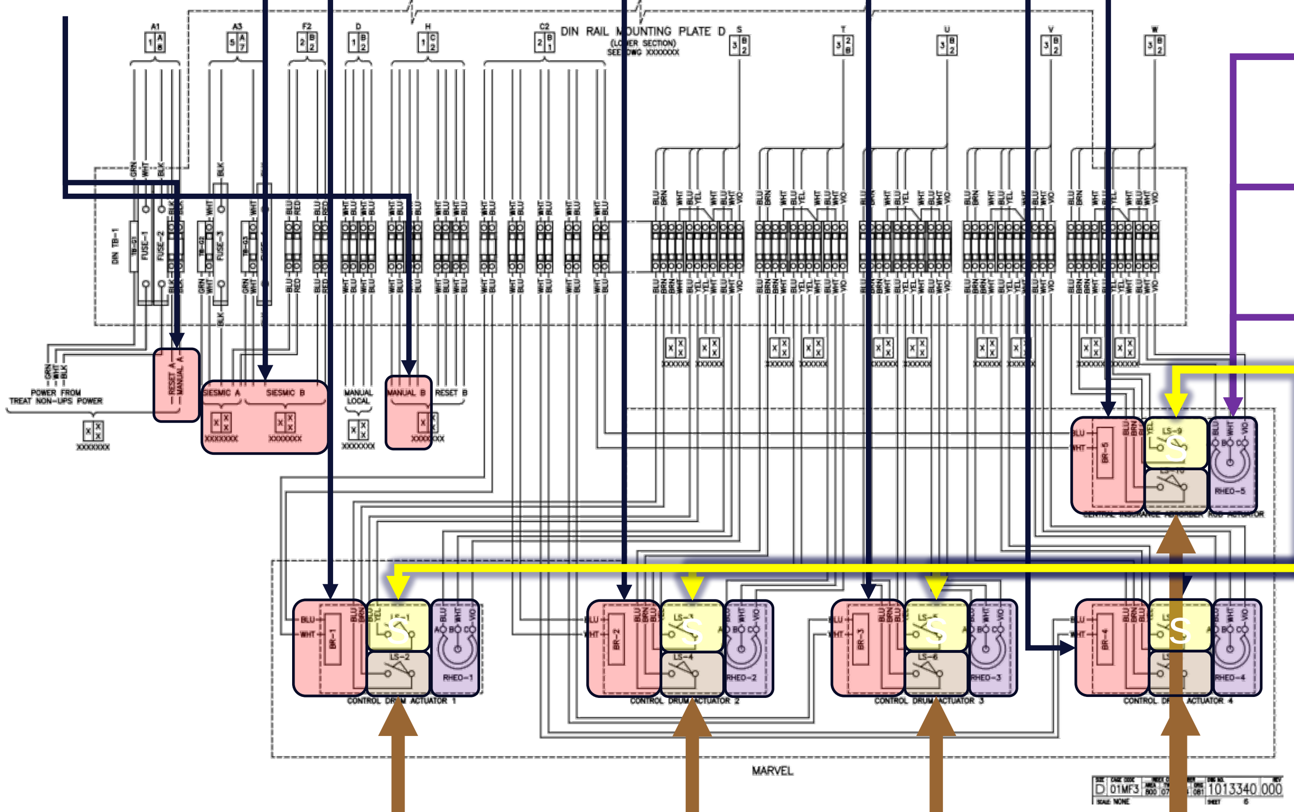
Position Indication

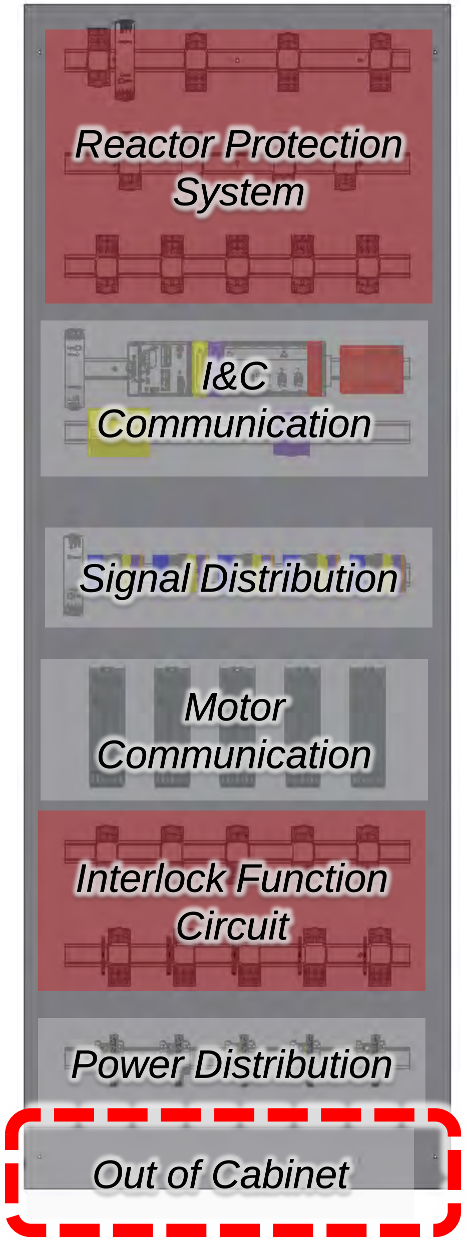
Drum Position Discrepancy

Control Drum Max Insertion Signal

Control Drum Shutdown Limit Signal

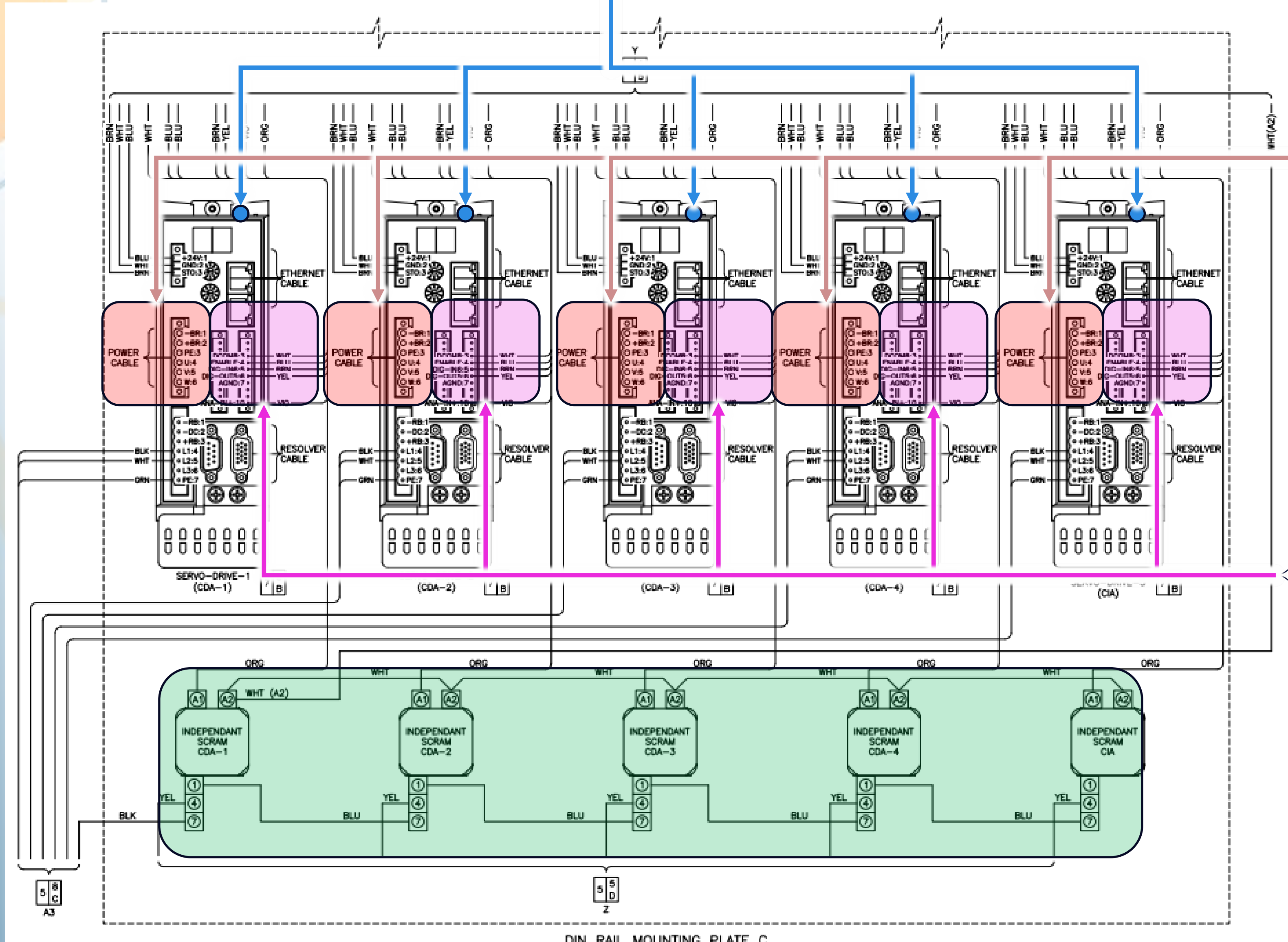
Safe Shutdown Verification





CD, CIA, and Interlock Electric Requirements

Control Drum Data Transmission

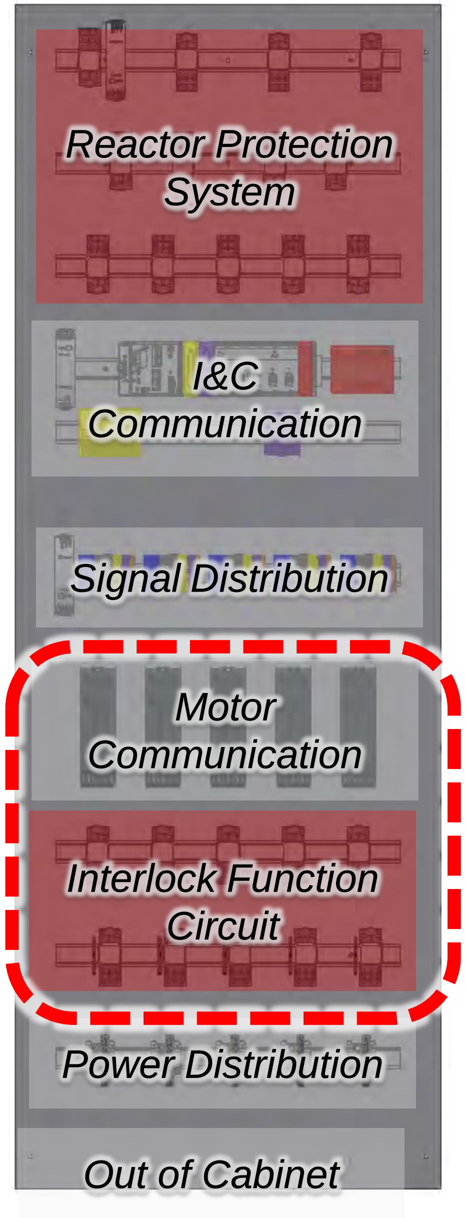


Motor Overcurrent

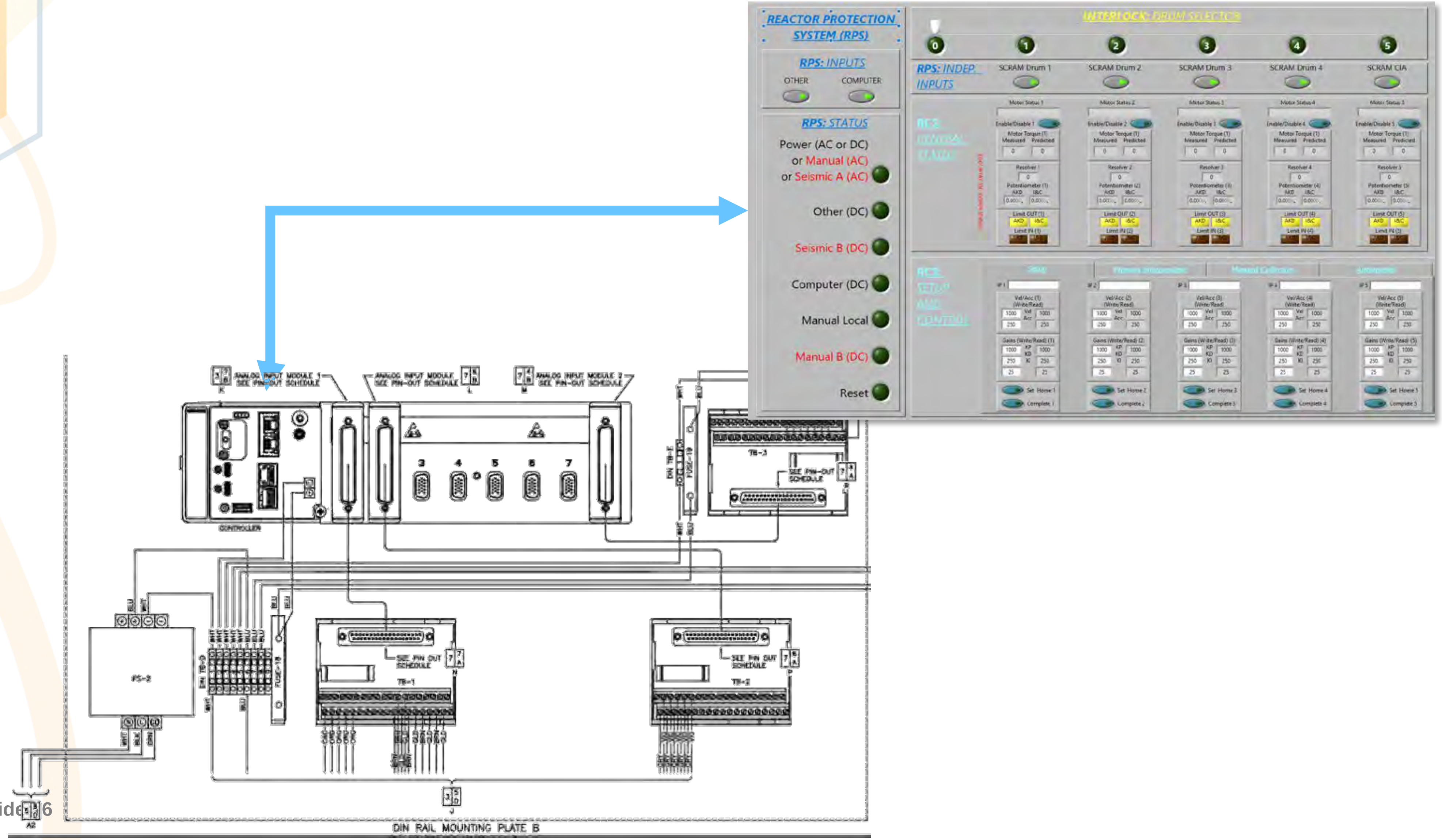
CD Motor and Shaft Pos. Measurement

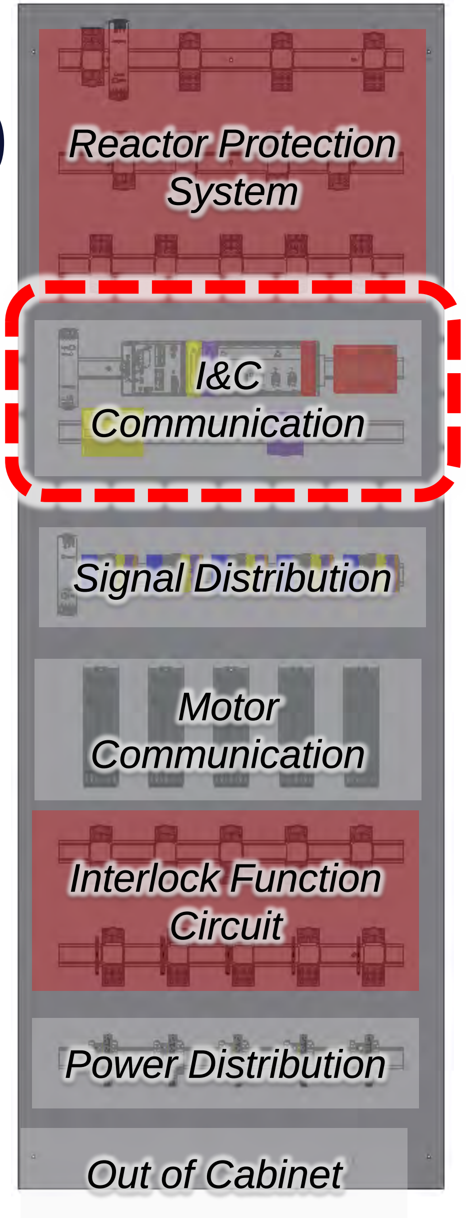
CIA Motor and Rod Pos. Measurement

Drum Position Discrepancy



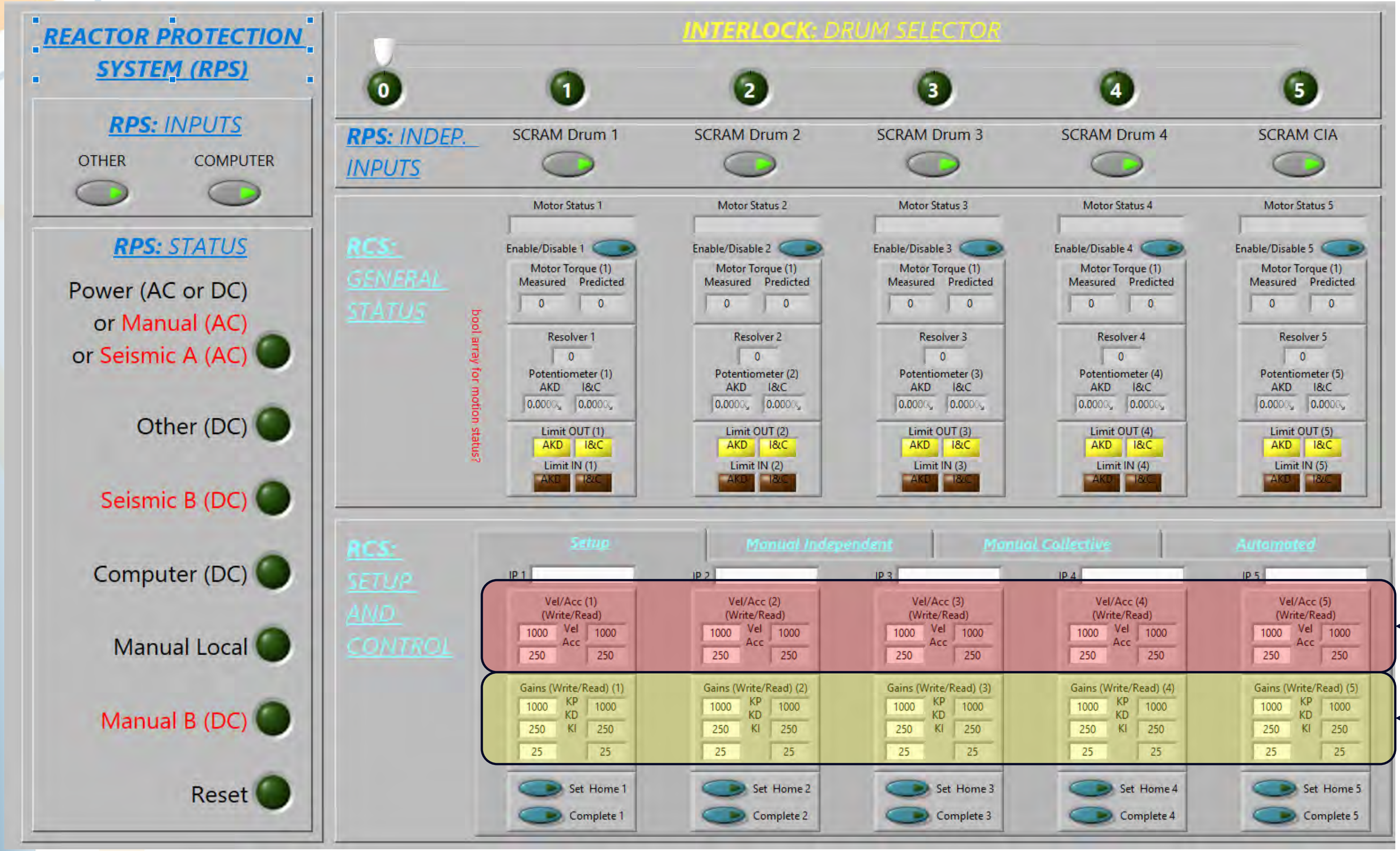
RCS, Interlocks, & RPS interface with I&C (software)





CD and CIA Software Requirements

- Disclaimer: PROTOTYPING Software for RCS, RPS, and Interlocks

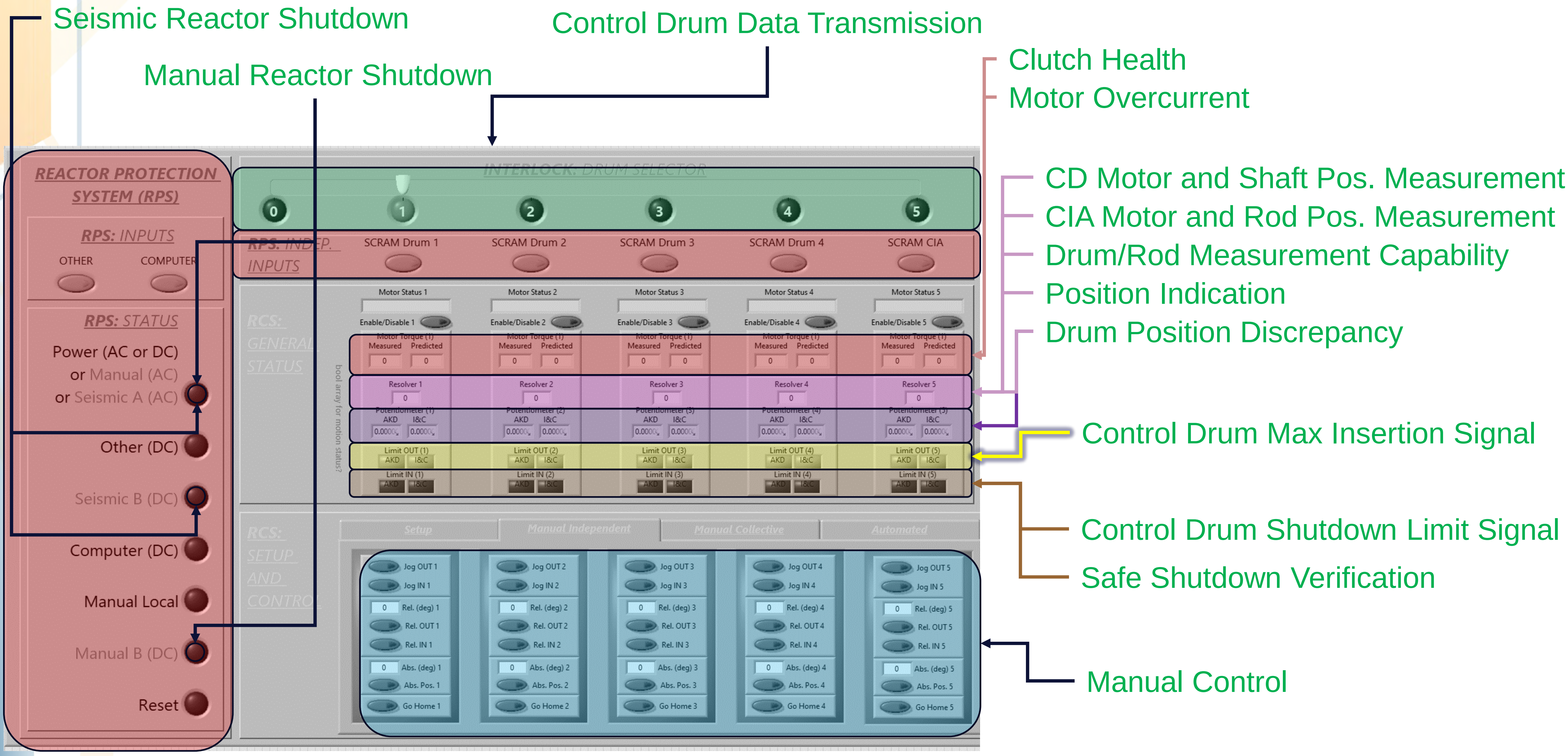


Drum Insertion Speed (RCS)

Note: Gain control enables target response tuning for better position/speed control influenced by inertia, spring constant, damping, and gear ratio

CD and CIA Software Requirements

- Disclaimer: PROTOTYPING Software for RCS, RPS, and Interlocks



Qualification Methods

- Each CD and CIA actuator will go through a checkout and assembly plan
- The qualification process in the double delta platform intends to load the systems to approximate the reactor application with some potential loadings being:
  - Expected deflections
    - Thermal expansions
  - Inertia
    - Drum geometry
  - Expected torques
    - Deflections at bearings
  - Potential thermal loads

Prototypes

Microreactor Program

Development and Prototyping Process (Current)

Prototype mechanical, electrical, software, qualification

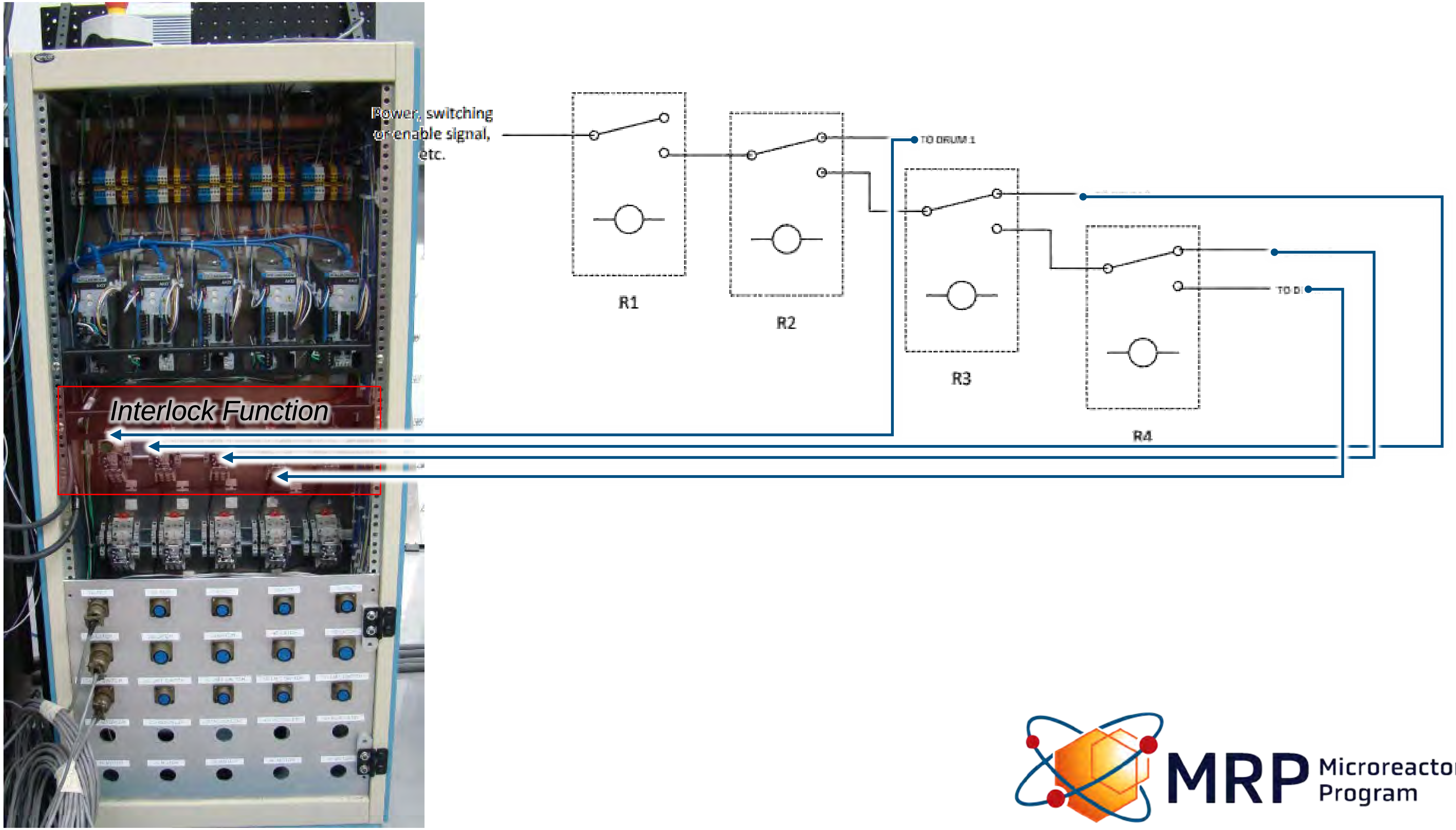
Mechanical

Electrical

Software

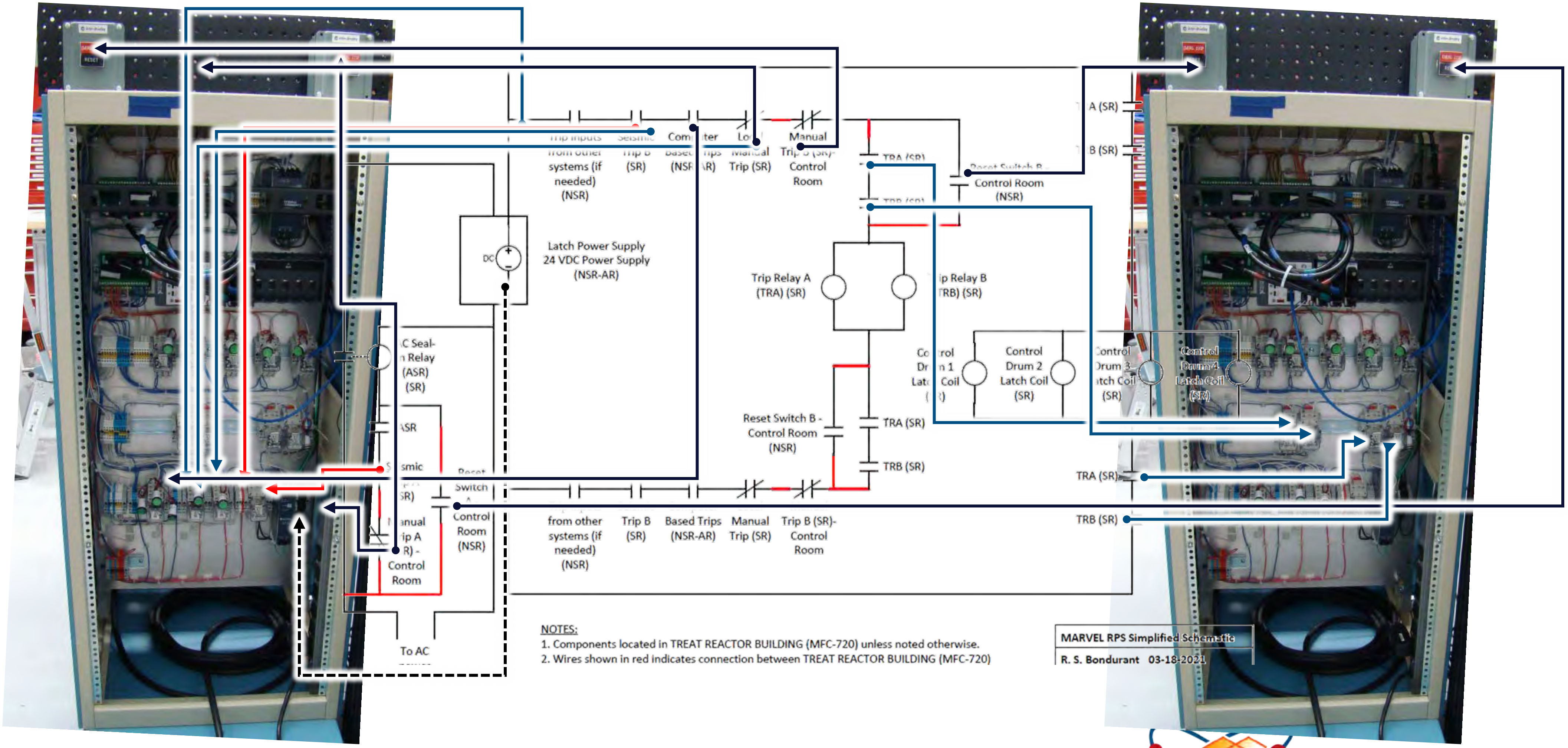
Qualification

Prototype Interlock



MRP Microreactor Program

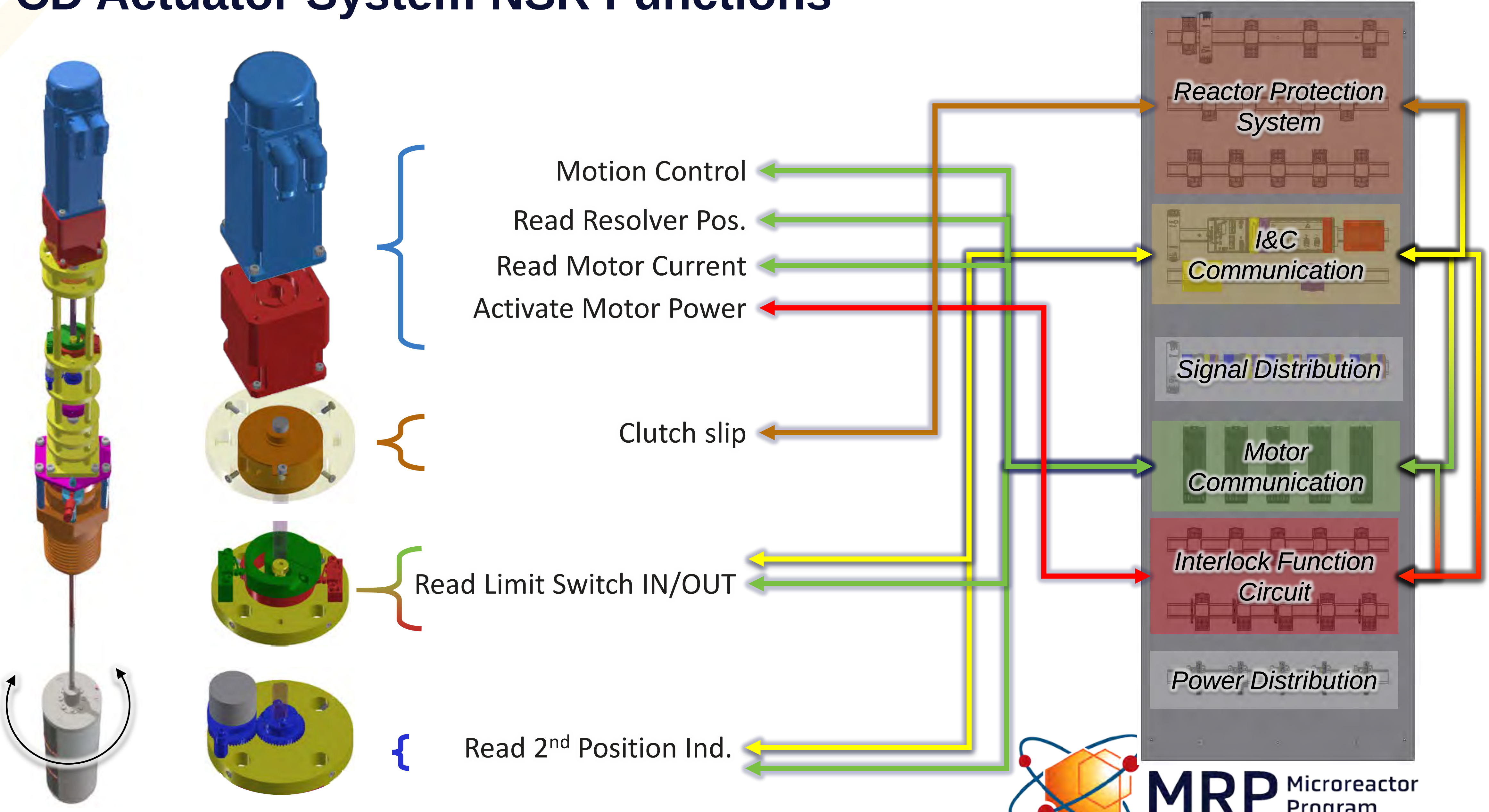
RPS Prototype



MRP Microreactor Program

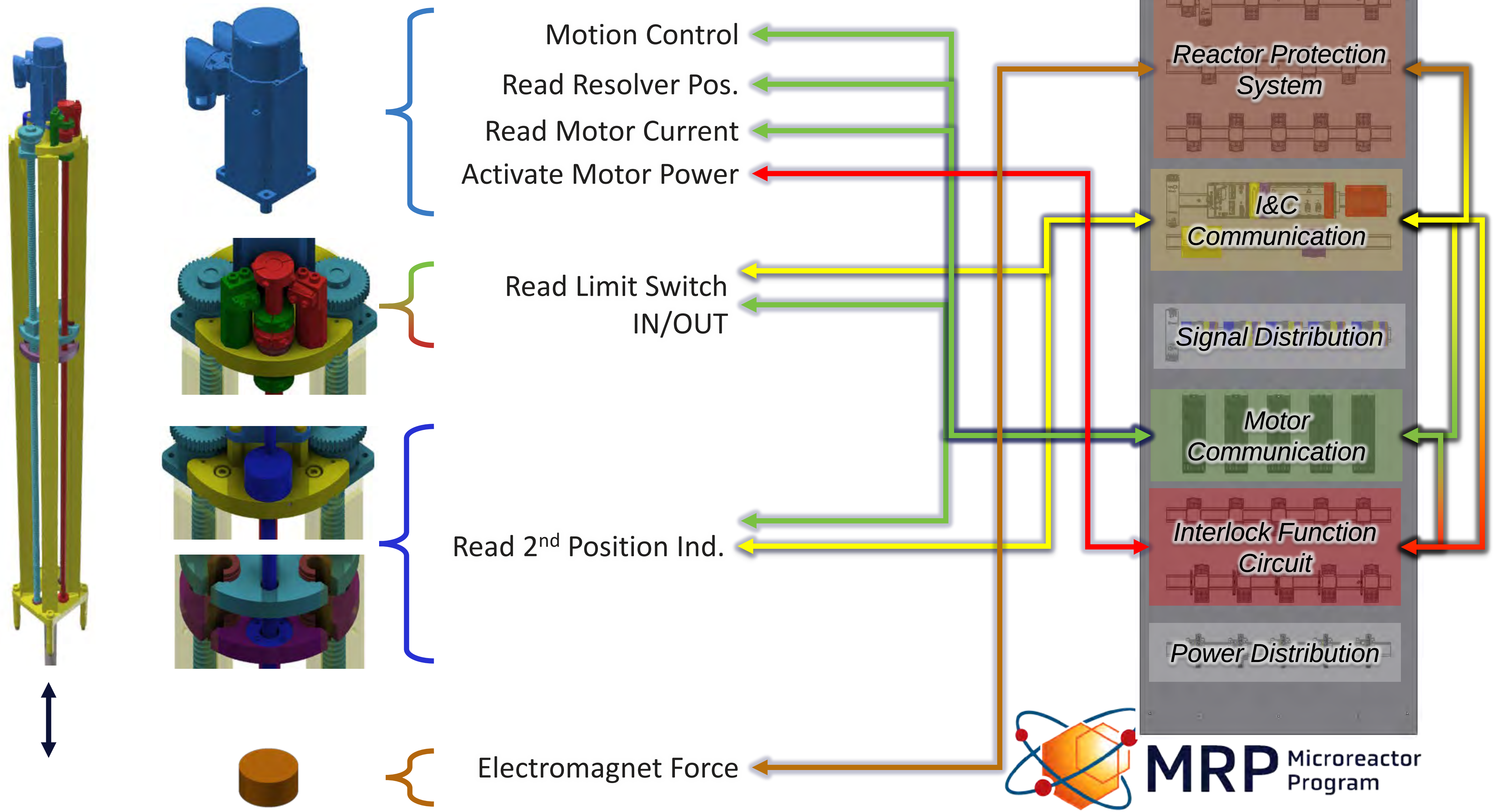
MRP Microreactor Program

CD Actuator System NSR Functions



MRP Microreactor Program

CIA Actuator System NSR Functions



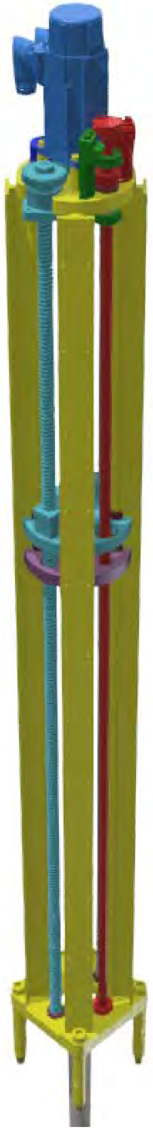
MRP Microreactor Program

CD System Primary Modes

- Pre-Operation:
  - Activate and check all systems
  - Adjust drum out hard stop to target
  - Home System against in hard stop
  - Independently Test SR Out Hard Stop for each Drum
  - Independently Test SR Scram for each Drum
- Operation
  - Move to target Sub Critical Setpoint
  - Move Drum to Critical Position
    - *Check criticality necessary systems*
  - Adapt Position Based on Criteria Such as Load Following
  - Demonstrate Hitting Drum Out Hard Stop
  - Controlled Shutdown
  - Scram as necessary

MRP Microreactor Program

CIA System Primary Modes



- Pre-Operation:
  - Adjust CIA hard stop to target if necessary
  - Activate and check all systems
  - Home System
  - Demonstrate Hitting Out Hard Stop
  - Test Scram
- Operation
  - Move to Top position
    - *check criticality measurement systems*
  - Demonstrate Hitting Out Hard Stop
  - Retain position during operation
  - Controlled Shutdown

MRP Microreactor Program