Instrumentation and Sensors

Instrumentation and Sensors - Microreactor Automatic Control System (MACS) Platform

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MACS' Motivation

- MACS is a hardware/software framework which is sufficiently enabled to test various reactor models and automatic control algorithms as part of a representative hardware environment
- Framework has promise in paving the way toward autonomous operation of microreactors, which is key to improve:
  - Performance
  - Operational efficiency
  - Cost competitiveness
- MACS helps advance microreactor instrumentation technology by enabling one to optimize:
  - Parameter, and thus corresponding sensor, selection
  - Communication architectures within the control scheme and
  - Optimize placement

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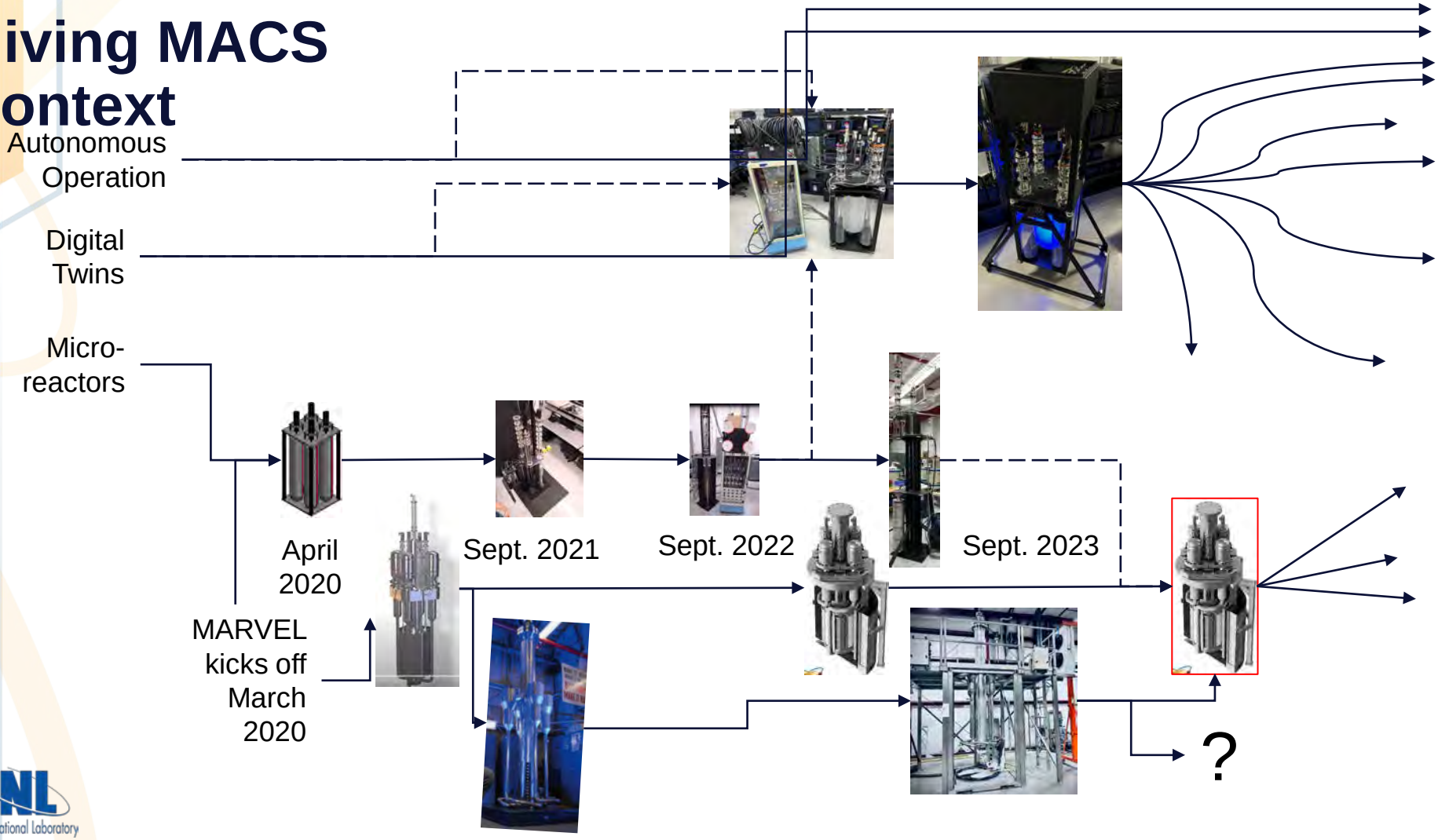
Giving MACS Context



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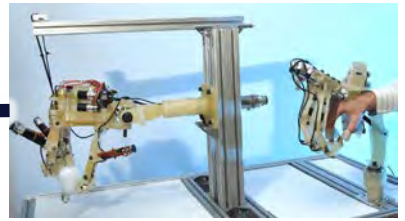
Giving MACS Competence

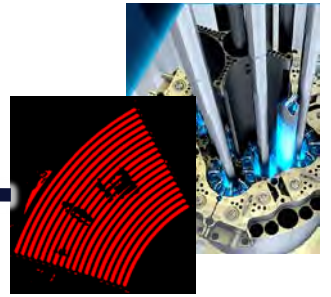
Environment Simulation

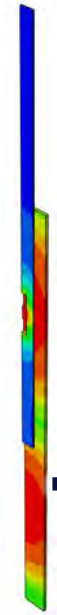
Motion Control

3D Volume interaction



Reactor Light Detection/ Processing





Discrete Mapping

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How can we make the MACS configurations most useful?

- General microreactor capabilities with accessible interfaces
  - Safety systems (hardware or simulated)
    - Interlocks
    - Reactor protection system, etc.)
  - Sensors
  - Digital system models
  - Control Schemes

- Framework
  - Structure to enable separate effects integration
    - Actuation
    - Reactor
    - Etc.

Cells: Useful in Biology, FEA, and MACS

- General Microreactor Systems
  - Reactor, Coolant, Power Extraction, Actuation, Control
- Hardware cells in MACS
  - Controller Cell
    - Base actuator functionality with plugs for external inputs/outputs
  - Actuation Cell
    - Near full functionality of MARVEL RCS
  - Reactor Cell
    - Non-nuclear surrogate
- Complete Microreactor representation is required for Autonomous control thus missing dynamic systems requires digital representation
  - Yeah, MACS does that.

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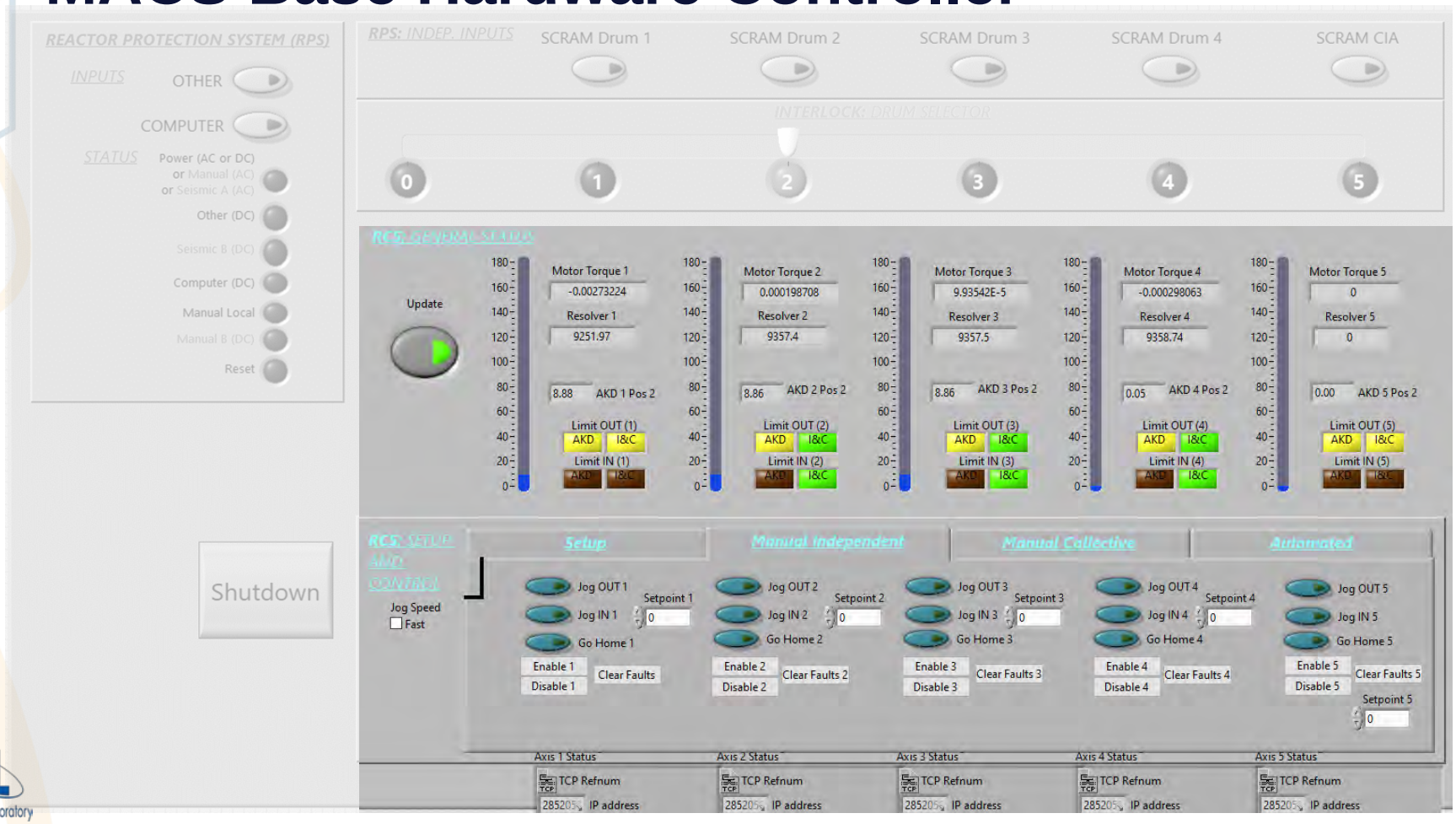
MACS Base Hardware Controller



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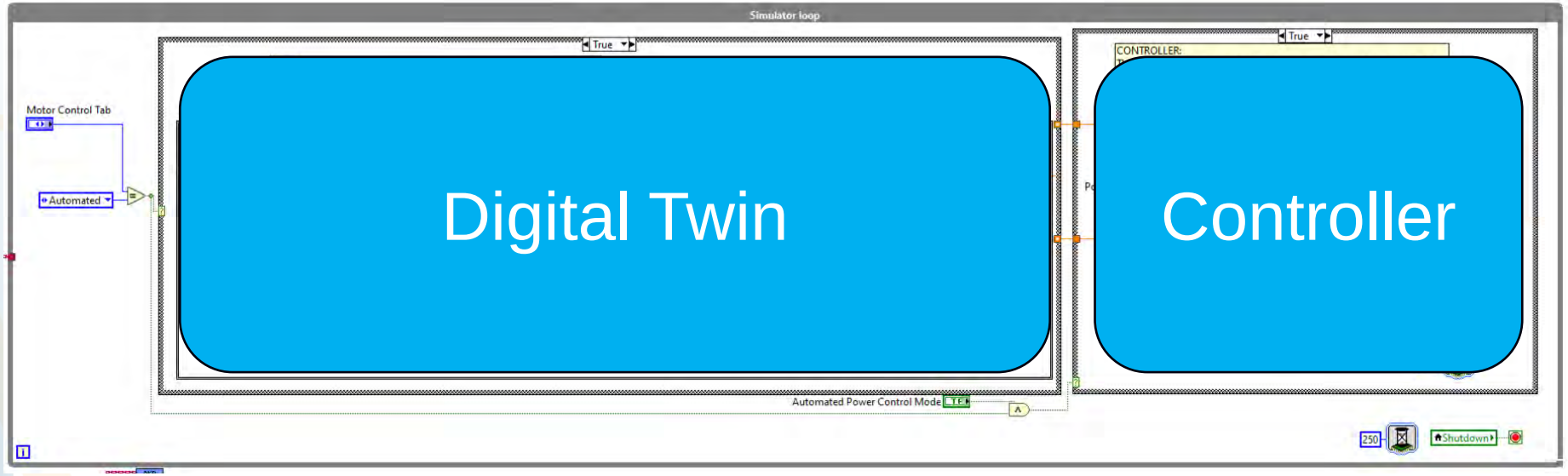
MACS Software plugs for sensor input or digital plant supplement and Controller Portions



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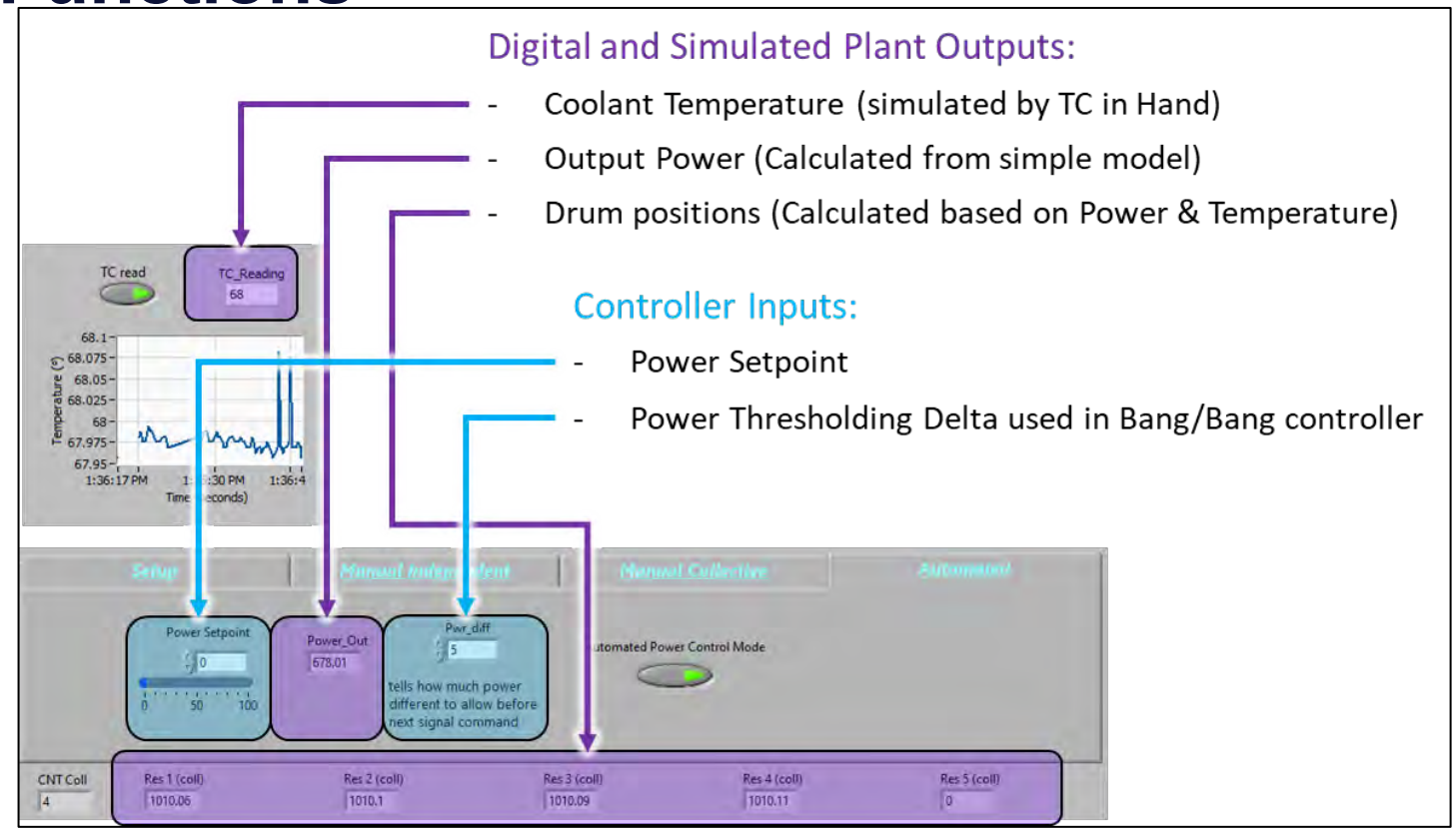
MACS Initial Test Case of 4 Automatic Functions



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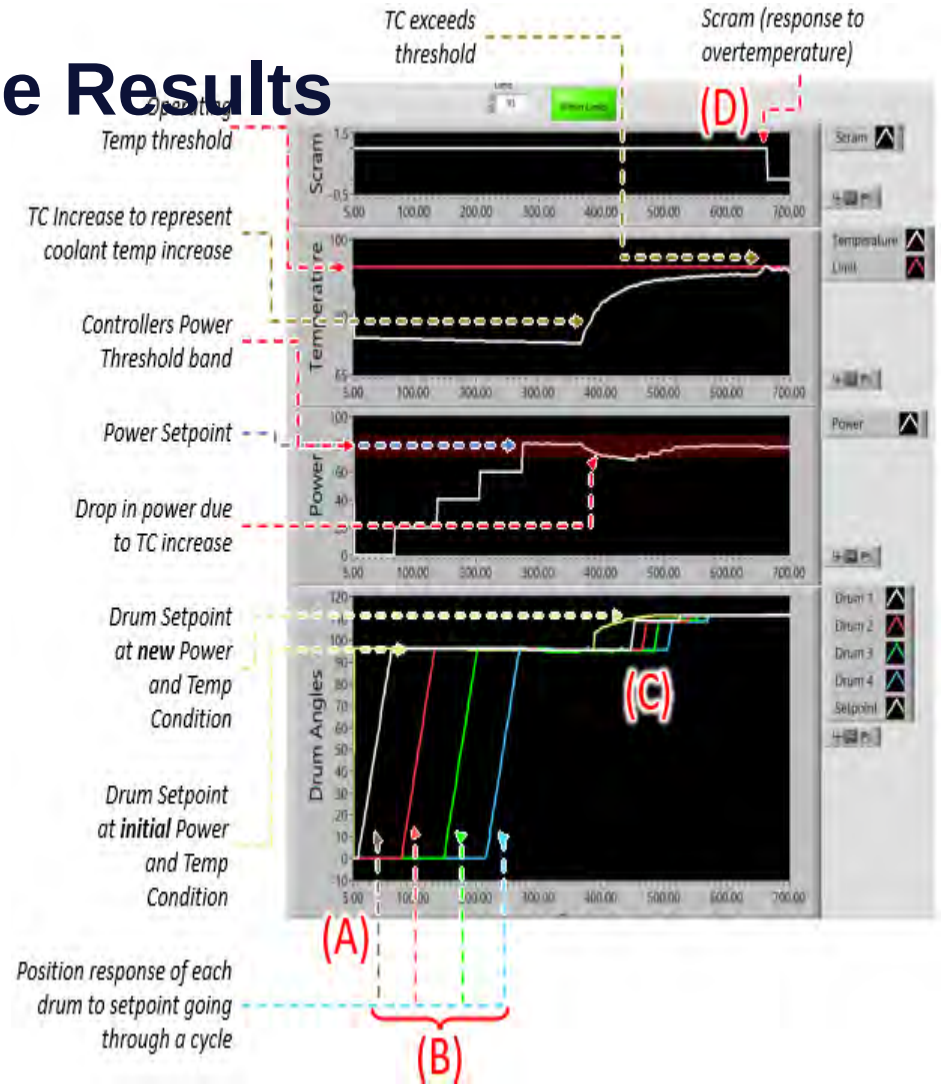
MACS Initial Test Case Results

A. Individual Setpoint Achievement
B. Four Drum Iteration
C. Power Setpoint Threshold Control
D. Overtemperature Scram



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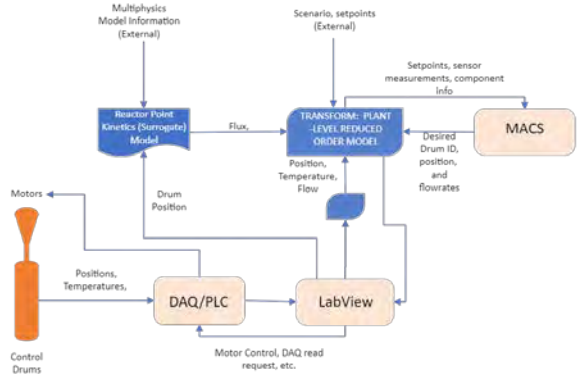
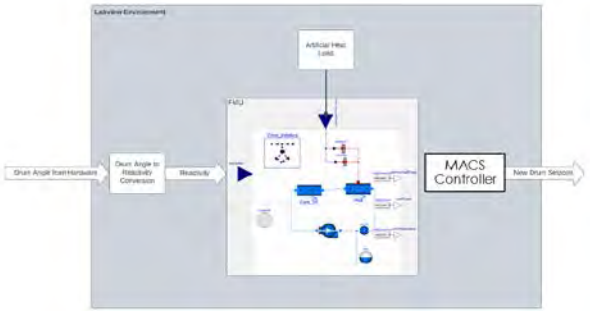
MACS

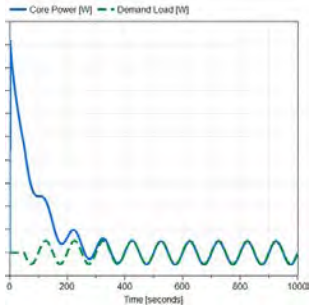
- Preliminary set of requirements defined in FY22
  - Reactor power control
  - Cooling medium
  - Power conversion unit
  - Surveillance and diagnostics
- MACS concept and design defined; implementation underway
  - Hardware control and DAQ using LabVIEW environment dictated some of the interface requirements
  - Functional mockup interface (FMI) standard leveraged for interoperability of surrogate models, control algorithms, and DAQ
- FY24 Goals: Demonstrate automated control under multiple operational scenarios within the MACS Platform



Conceptual Interfaces for MACS



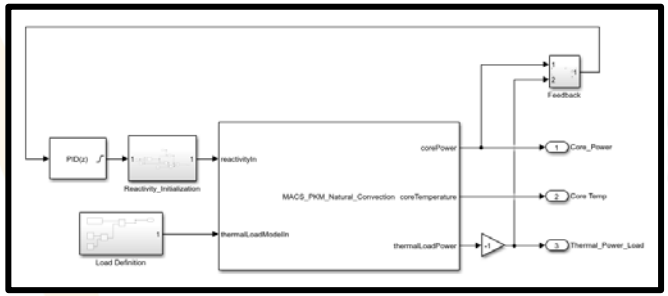
Schematic Showing Example FMU Integration



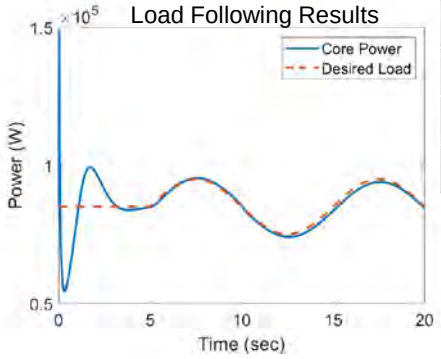
Example of Reactivity Control For Load Following

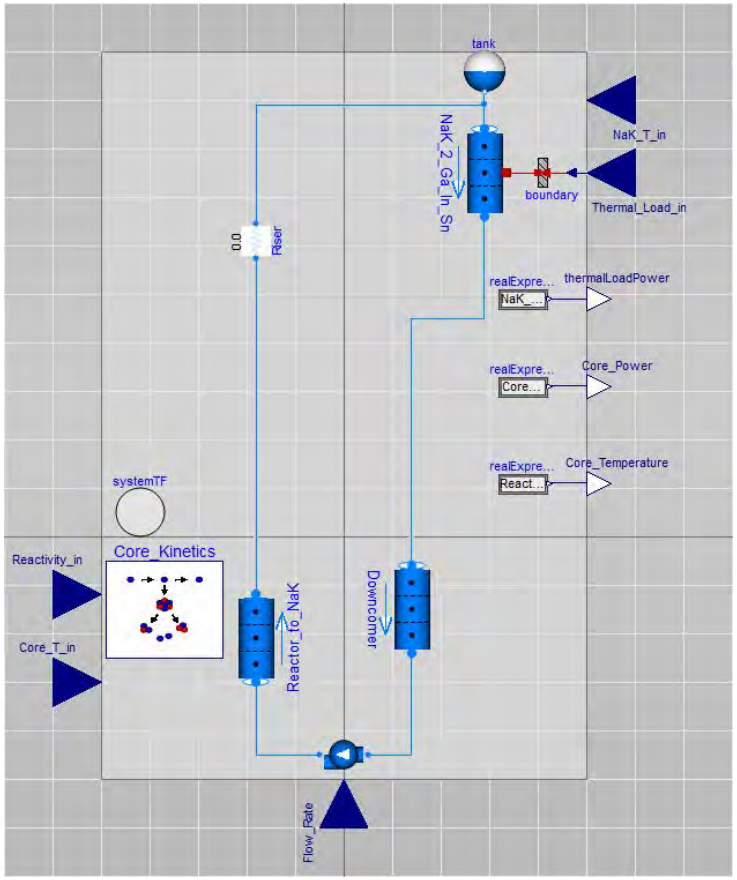
Microreactor Plant Model

- Modelica model generated using TRANSFORM Library
  - Captures the necessary geometry/parameter setpoints from reference design
- FMU generated for preliminary control and load following tests in Matlab/Simulink
- Refined FMU will be utilized for FMPy simulation and Python based Model Predictive Control for real-time interaction with gRPC protocol
- Performance/accuracy balance analysis being performed to determine the level of detail which can be modeled while maintaining real-time interaction with the gRPC protocol



Simulink Control Study

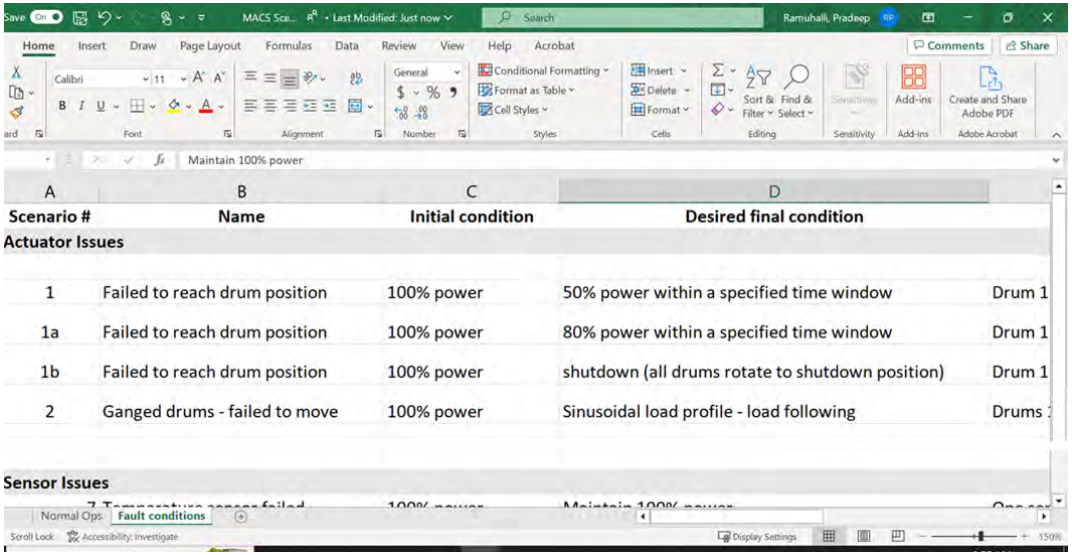




Modelica Model

Scenarios

- Several scenarios defined
- Nominal
  - Startup
  - Power ramp up/down
  - Load following
- Off-normal
  - Sensor issues
  - Actuator issues
  - Operator errors



Maintain 100% power

Scenario #	Name	Initial condition	Desired final condition	
Actuator Issues				
1	Failed to reach drum position	100% power	50% power within a specified time window	Drum 1
1a	Failed to reach drum position	100% power	80% power within a specified time window	Drum 1
1b	Failed to reach drum position	100% power	shutdown (all drums rotate to shutdown position)	Drum 1
2	Ganged drums - failed to move	100% power	Sinusoidal load profile - load following	Drums
Sensor Issues				

Example Set of Scenarios for MACS Controller Tests

Discussion?

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References

- https://www.youtube.com/watch?v=5I925aHIoVE
- https://gain.inl.gov/SiteAssets/MicroreactorProgram/2023MicroreactorProgramWinterReview/TechnologyMaturation-2023.pdf
- https://www.ans.org/news/article-3951/profile-published-on-head-of-marvel-project-at-idaho-national-laboratory/
- https://gain.inl.gov/2022MARVELTechRevPresentations/1.07-Crawford_ReactivityControlSystem_2022MARVELTechReview_19Oct22.pdf
- https://gain.inl.gov/SiteAssets/MicroreactorProgram/2022MicroreactorProgramWinterReview/MA_WinterReviewPresentation_2022.03.04.pdf
- https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_38634.pdf
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