# Microreactor Program Synergy with ASI

## ASI Program Review 2023

November 2, 2023


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# DOE Microreactor Program – 2023

## ***Program Vision***

***Through cross-cutting research and development and technology demonstration support, the Microreactor Program will enable broad deployment of microreactor technology by:***

- Achieving technological breakthroughs for key features of microreactors
- Identifying and addressing technology solutions to improve the economic viability and licensing readiness of microreactors.
- Enabling successful demonstrations of multiple domestic commercial microreactors.

## ***Program Objectives***

- Address critical cross-cutting R&D needs that require unique laboratory/university capability or expertise
- Develop R&D infrastructure to support design, demonstration, regulatory issue resolution, and M&S code validation
- Develop advanced technologies that enable improvements in microreactor viability

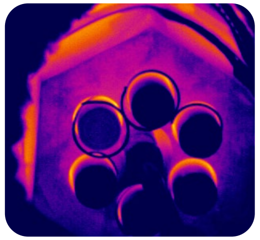
Technology Readiness Level

**Microreactor Application**

- Integrated Nuclear Testing
- Applied R&D

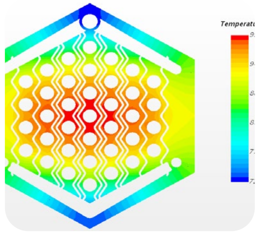

**Demonstration Support Capabilities**

- Non-nuclear Testing
- Test-beds for developers/regulators



**Technology Maturation**

- Matures fundamental microreactor enabling technologies and capabilities



**System Integration & Analyses**

- Identification of technology and regulatory gaps for Microreactors

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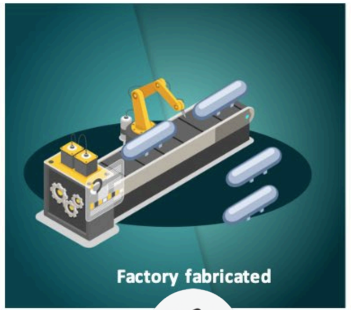
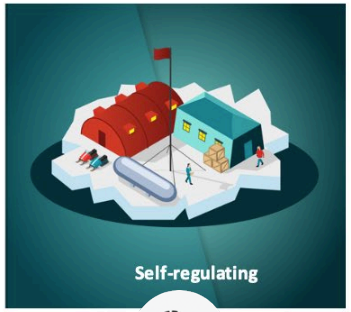
# Microreactor R&D
## Megawatt-scale Advanced Nuclear Reactors





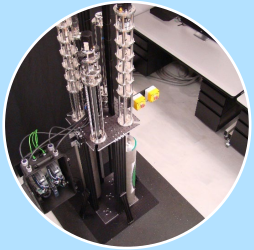



### ENABLING TECHNOLOGIES

#### Fuel & Moderator

- Small Core,
- Long life,
- HALEU
- High-T Moderator

#### Reactor Controls



- Automation
- Compact, in-core sensors
- AI/ ML
- Remote Control

#### Power Conversion

- Skid mounted
- High Temp.
- Robust
- Flexible operation

#### Structural Material

- Creep resistance
- ASME Sec III, Div. 5 compliant
- NQA-1 supply chain

#### Neutron Reflector


- Low cost
- Manufacturability
- High moderating ratio
- High temperature

#### Transport & Siting

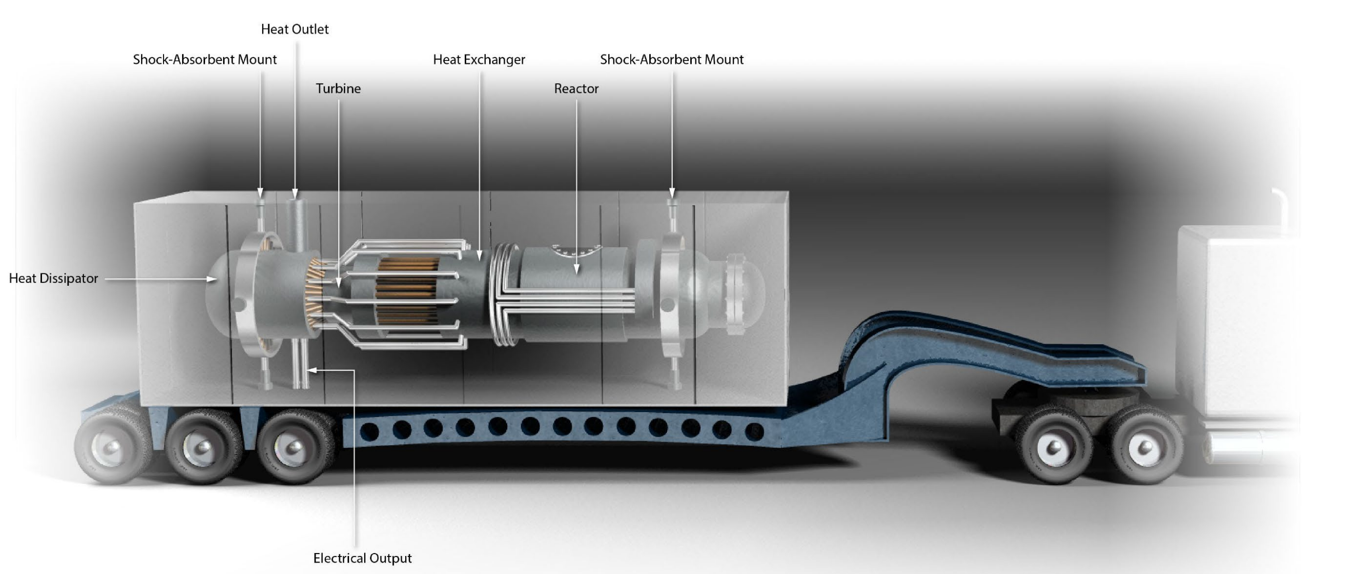

- NEPA
- Vibration isolation
- Transport shielding
- Licensing modernization

# Microreactor I&C Needs

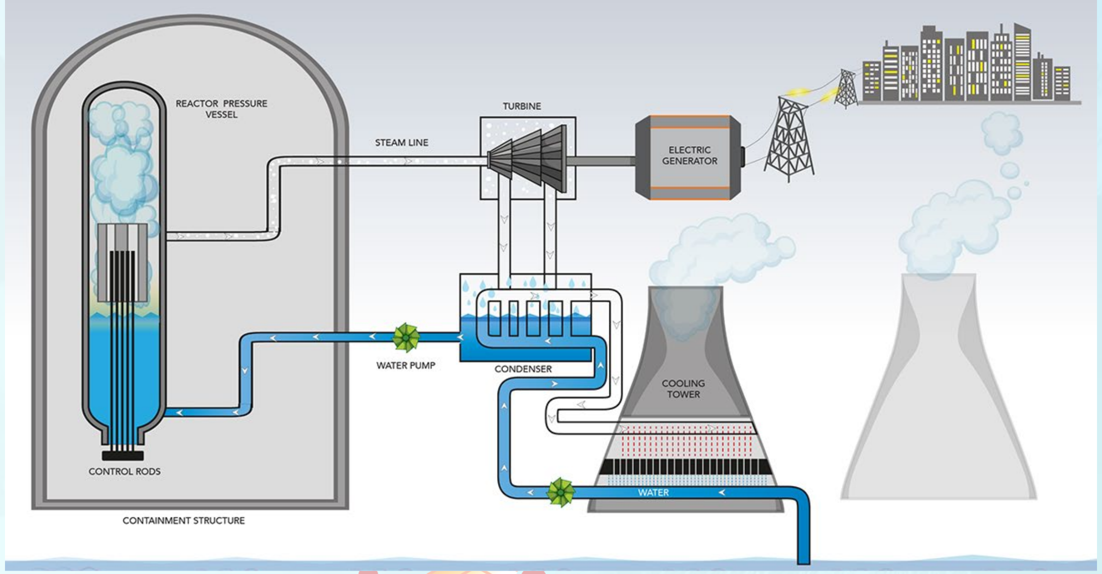
MACS task

- Smaller size, factory assembled, need for more automated or autonomous operation to reduce O&M costs without economies of scale
- Critical components such as pumps, heat exchangers and turbines may be located closer to the core in a harsher environment with limited access
  - Challenging to monitor or inspect, could benefit from advanced monitoring techniques
  - Harsher environment also more challenging for sensors

Acoustics task



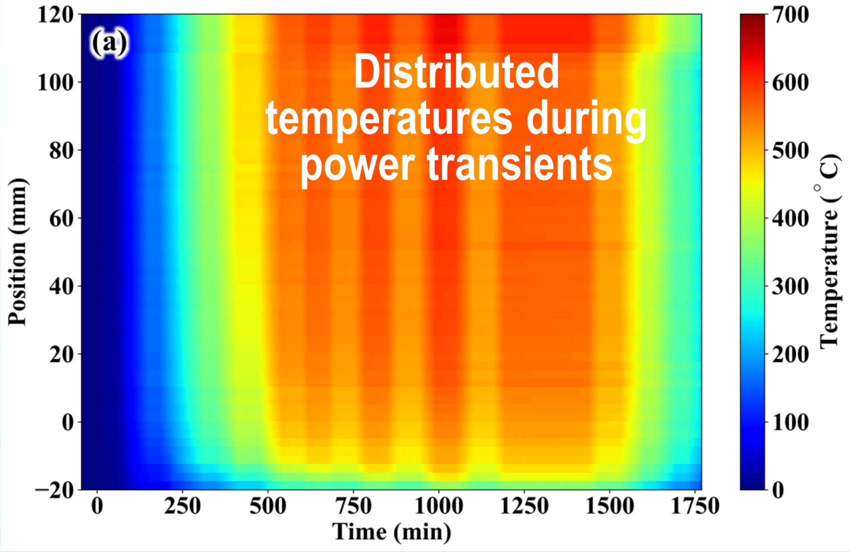

**Microreactor**
https://inl.gov/trending-topic/microreactors/

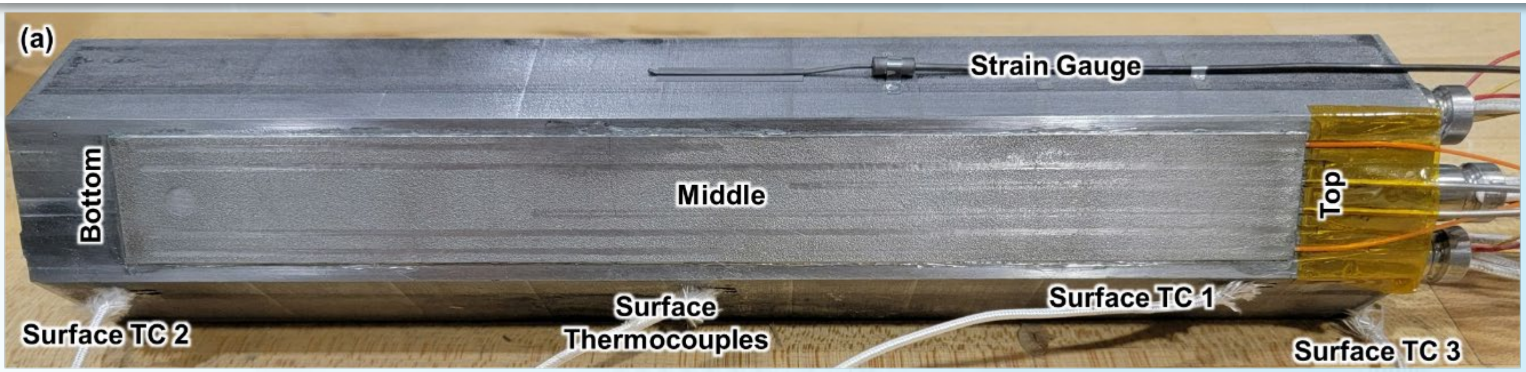


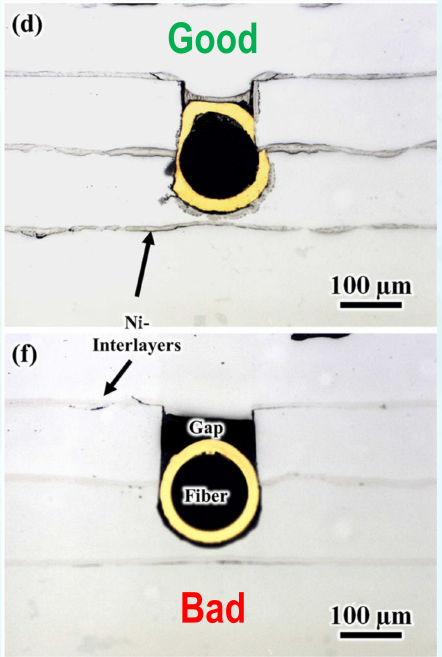

**Conventional reactor**
https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work

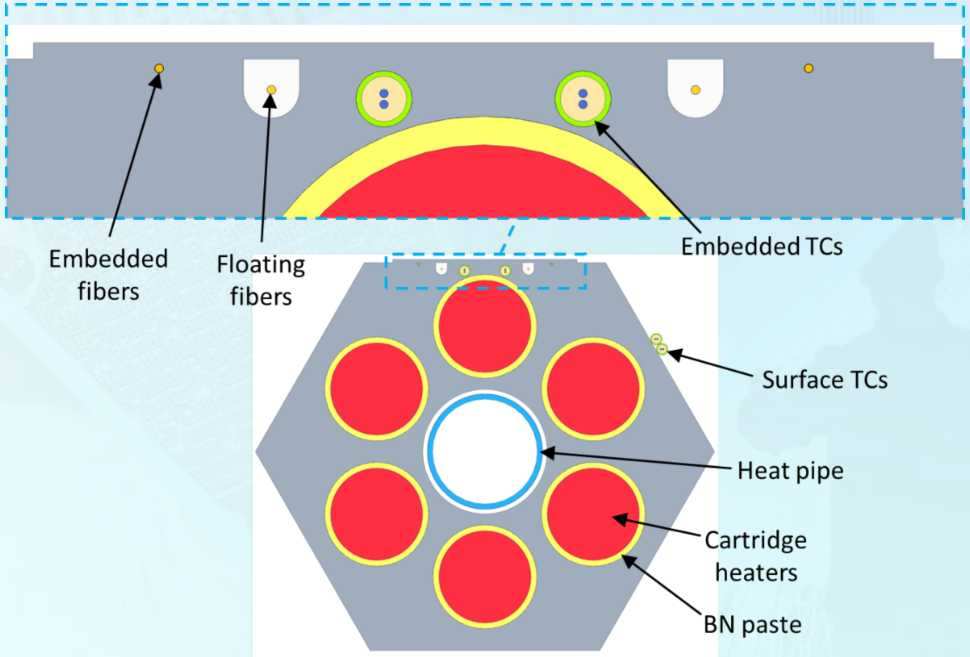
# Embedding Sensors in Hex Block for Heat Pipe-Based Microreactor

- Interest: Distributed temperature and strain during non-nuclear testing of a hex block with electrical heating of a heat pipe
- Ultrasonic additive manufacturing (UAM) process optimized for embedding fiber optics in stainless steel components [1]
- Initially measured thermal strain but failed due to differential thermal expansion (would benefit from higher temperature embedding process)
- More recently transitioned from monitoring static strain to dynamic (acoustic) strain



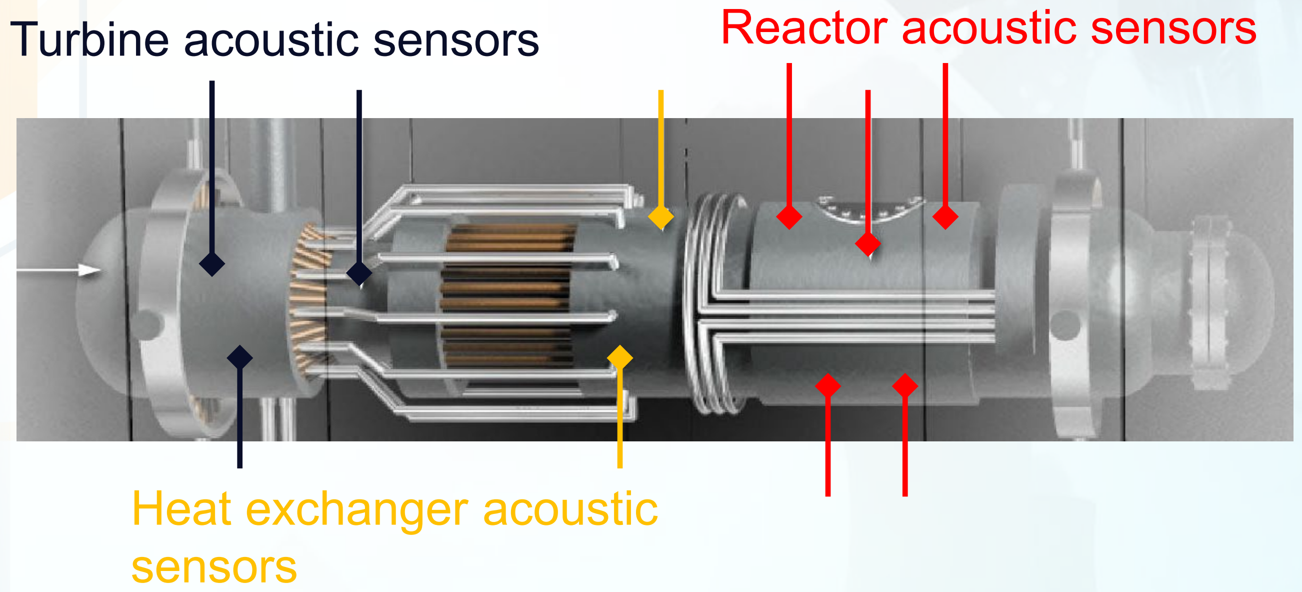



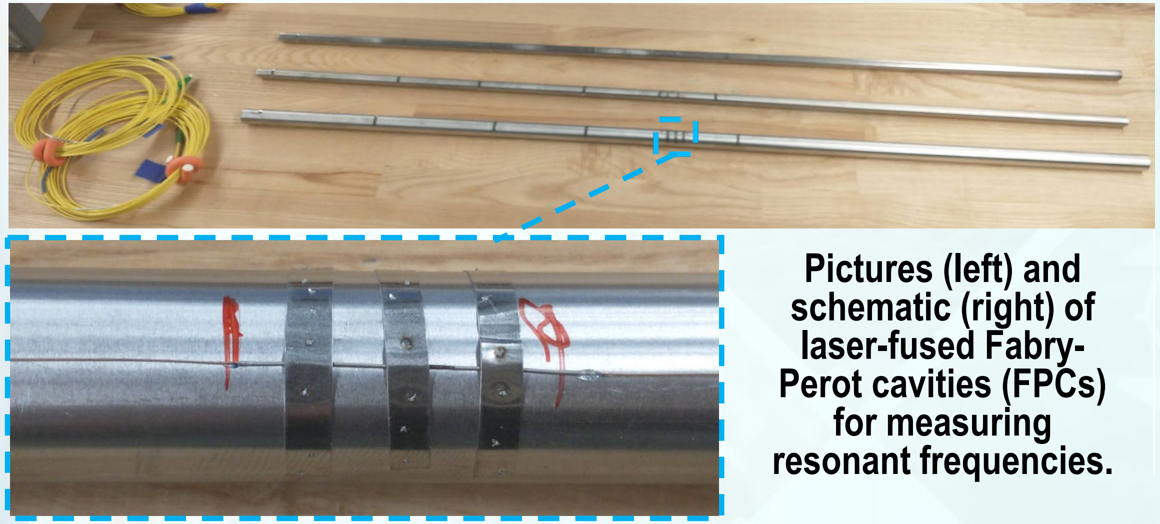





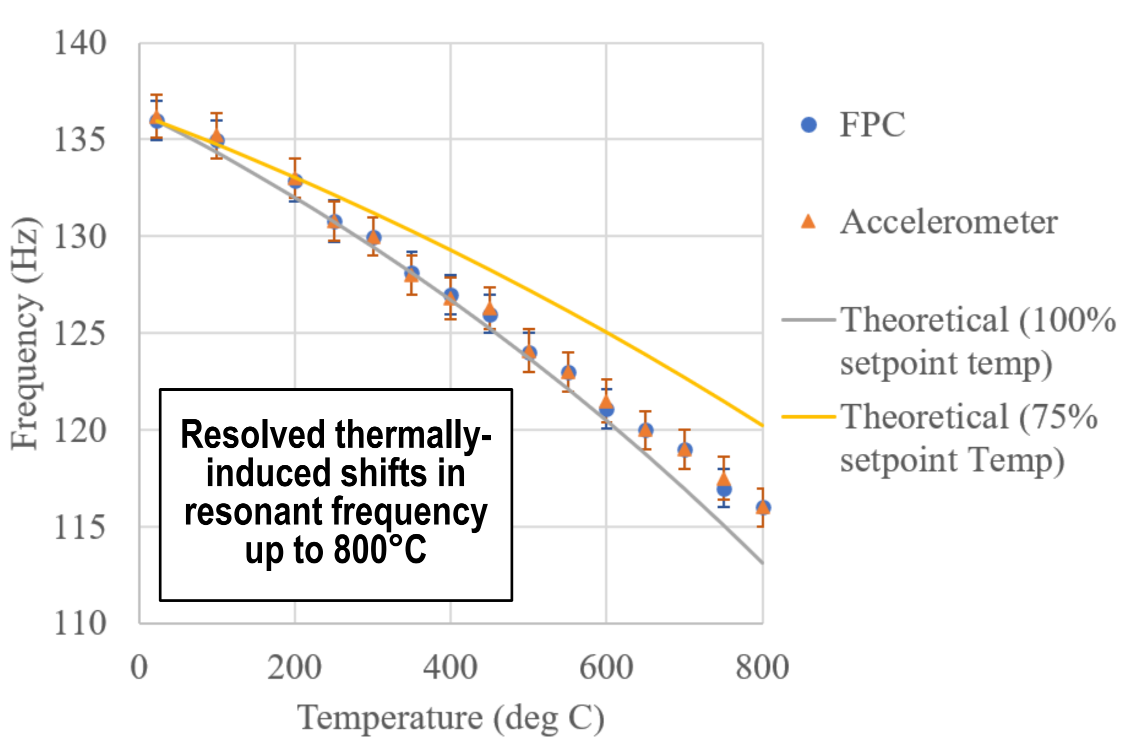
[1] H.C. Hyer, D.C. Sweeney, and C.M. Petrie, "Functional fiber-optic sensors embedded in stainless steel components using ultrasonic additive manufacturing for distributed temperature and strain measurements," *Additive Manufacturing* **52** (2022) 102681.

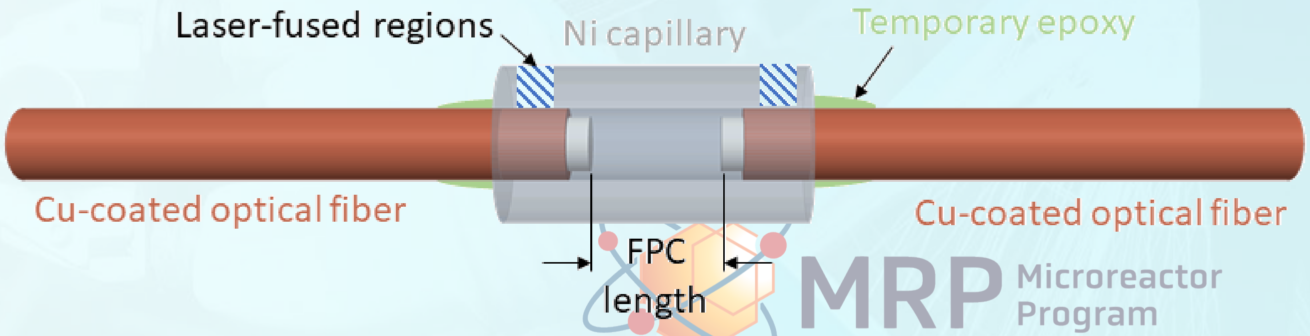
# Current Scope: Fiber Optic Acoustic Sensors



Pictures (left) and schematic (right) of laser-fused Fabry-Perot cavities (FPCs) for measuring resonant frequencies.

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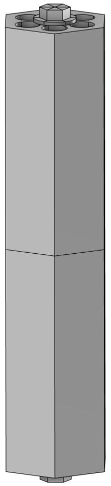
# Acoustics: Can we leverage resonance from ambient vibrations to monitor for structural changes?

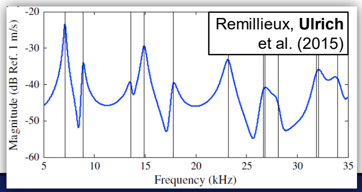
*Experiment*

**Acoustic testing of stressed core-block proxy**

intact and damaged



*Methods*

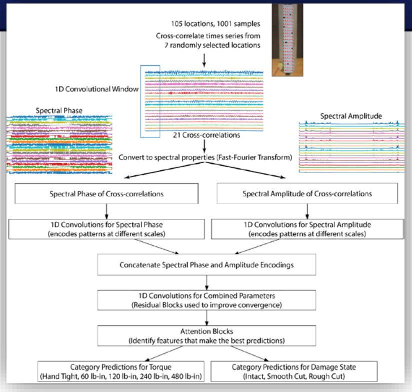



**Resonant Ultrasound Spectroscopy**

**linear & nonlinear**

**Machine Learning**

neural network




*Outcomes*

**Elastic material properties**

**Identify variations in stress & damage states**

**Inform future embedded sensing designs**

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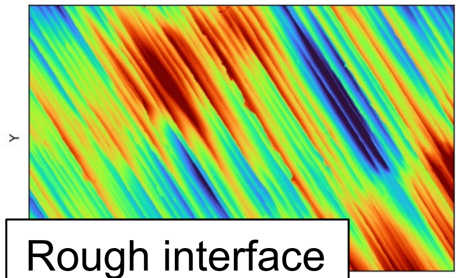
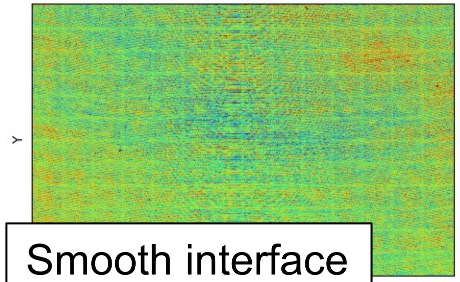
# Demonstration test matrix and operational relevance

*Monitoring Setting*

| | | **Operational** | **Demonstration** |
|---|---|---|---|
| | *Measure* | Embedded fiber optics | Laser vibrometer |
| *Component status* | **Stress** | Thermal gradients | Mechanical compression |
| | **Damage** | Fatigue, embrittlement | Joint created in test article |

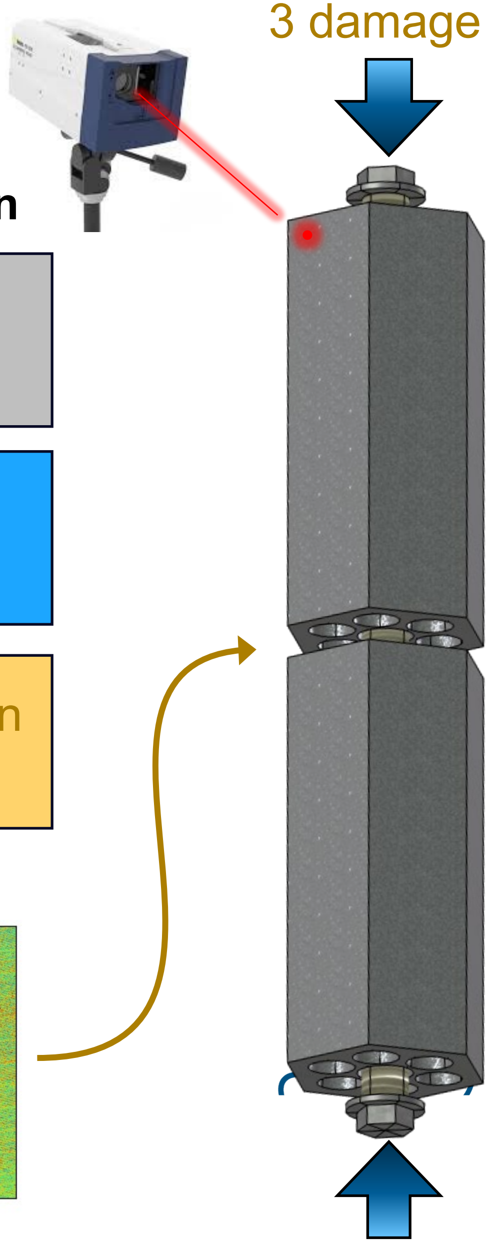


Rough interface



Smooth interface

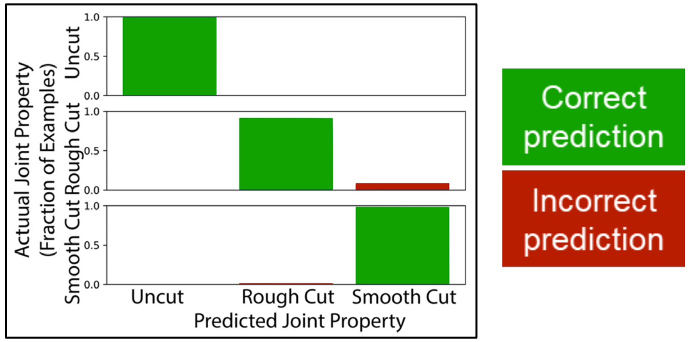
105 scan points
6 stress states
3 damage states

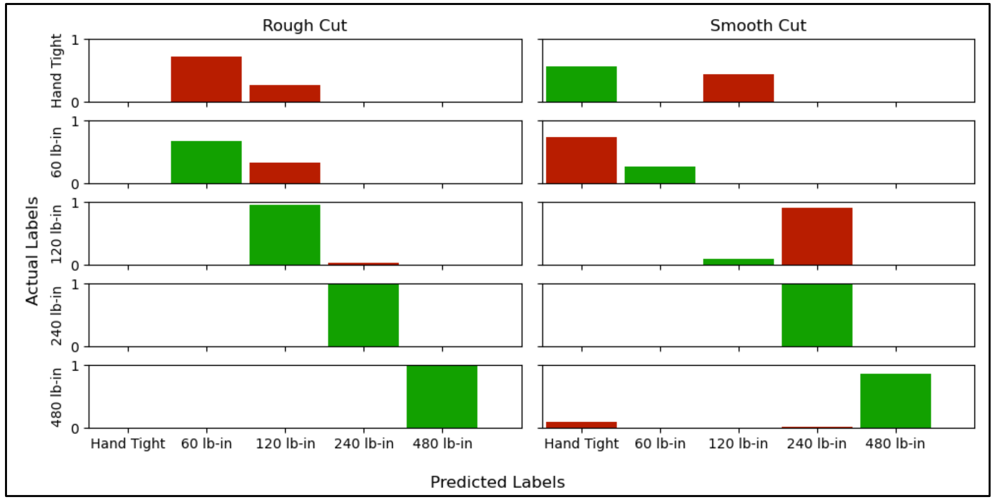


oreactor
rogram

# Machine learning predictions of structural status

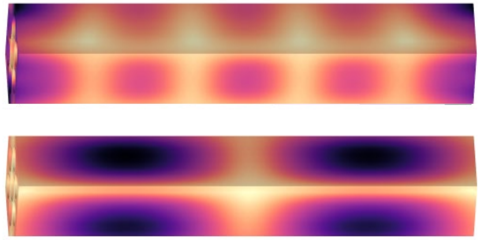
- 94% accuracy of component's stress state
- 100% detection of damage state
  - 94% accuracy of interface roughness
- 60 – 75% accuracy of combined stress & damage predictions




# FY24 Goals

- Better informed machine learning models using improved mode shape images
- Damage localization from reprocessed FY23 data



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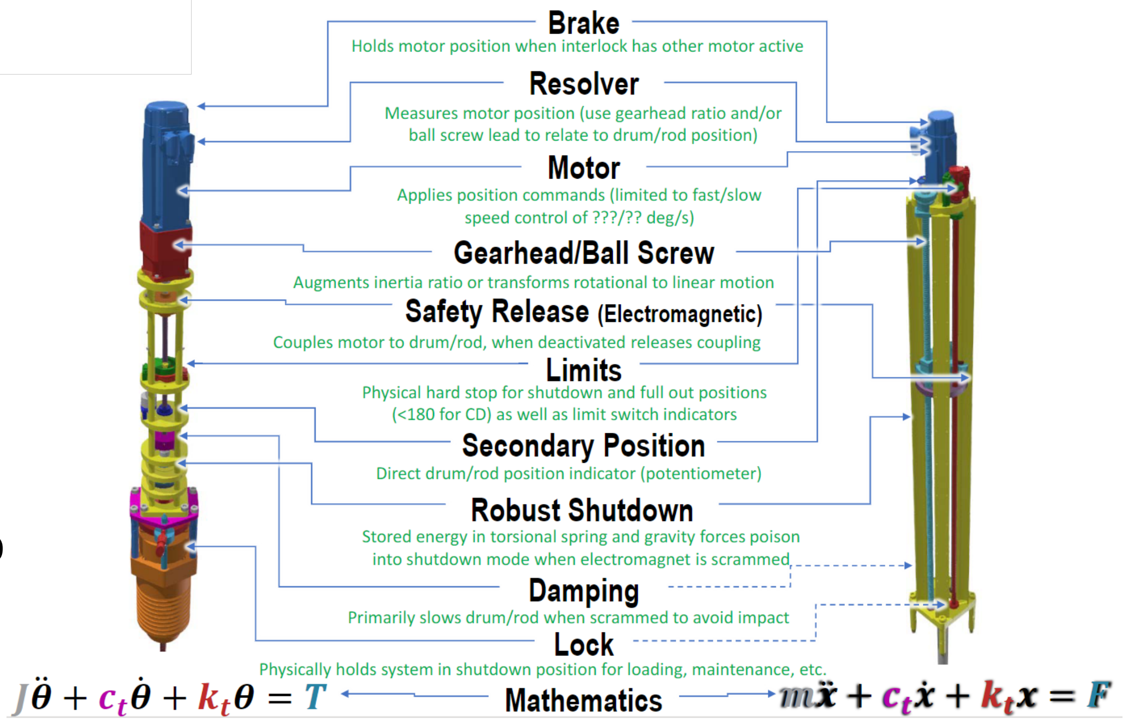
# Microreactor Automated Control System (MACS)

- Objective: Leverage prior research outputs to develop, test and implement a high fidelity and robust microreactor automated control system (MACS) that can perform with minimal need for human-in-the-loop action.
- Approach:
  - Leverage existing designs for microreactors, available testbeds, and prior research on control systems
  - Expected data/measurements: Reactor temperature, control element (drum or rod) positio coolant temperature and energy transfer to heat sink, and factors such as reactivity feedback, etc.
  - Hardware-In-The-Loop (HIL) simulator (MACS Platform), including heat and simulated reactivity to demonstrate capability

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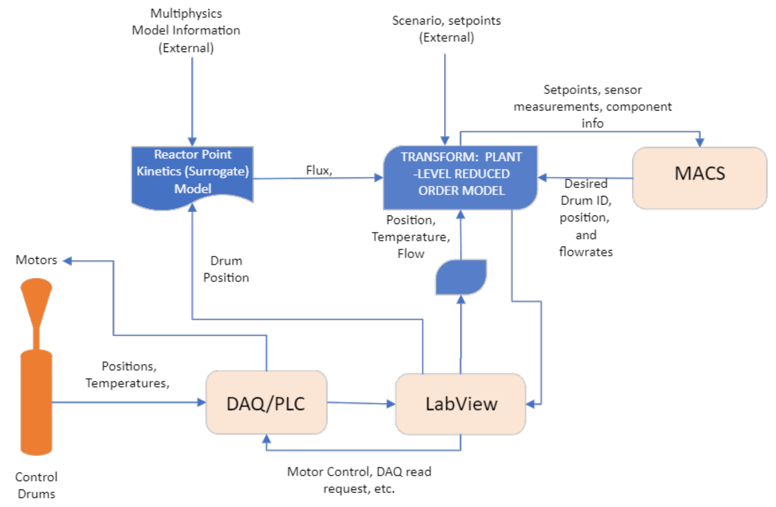
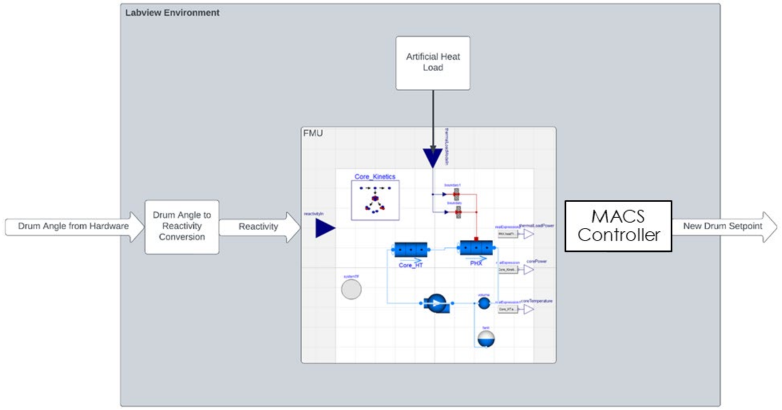
# MACS

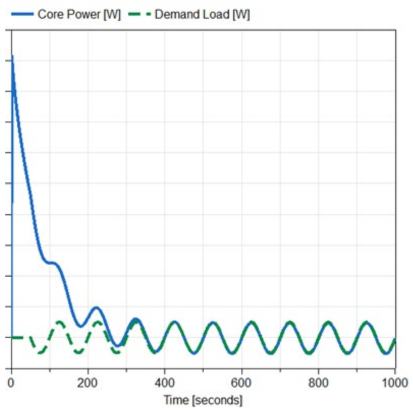
- Preliminary set of requirements defined in FY22
  - Reactor power control
  - Cooling medium
  - Power conversion unit
  - Surveillance and diagnostics
- MACS concept and design defined; implementation underway
  - Hardware control and DAQ using LabVIEW environment dictated some of the interface requirements
  - 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

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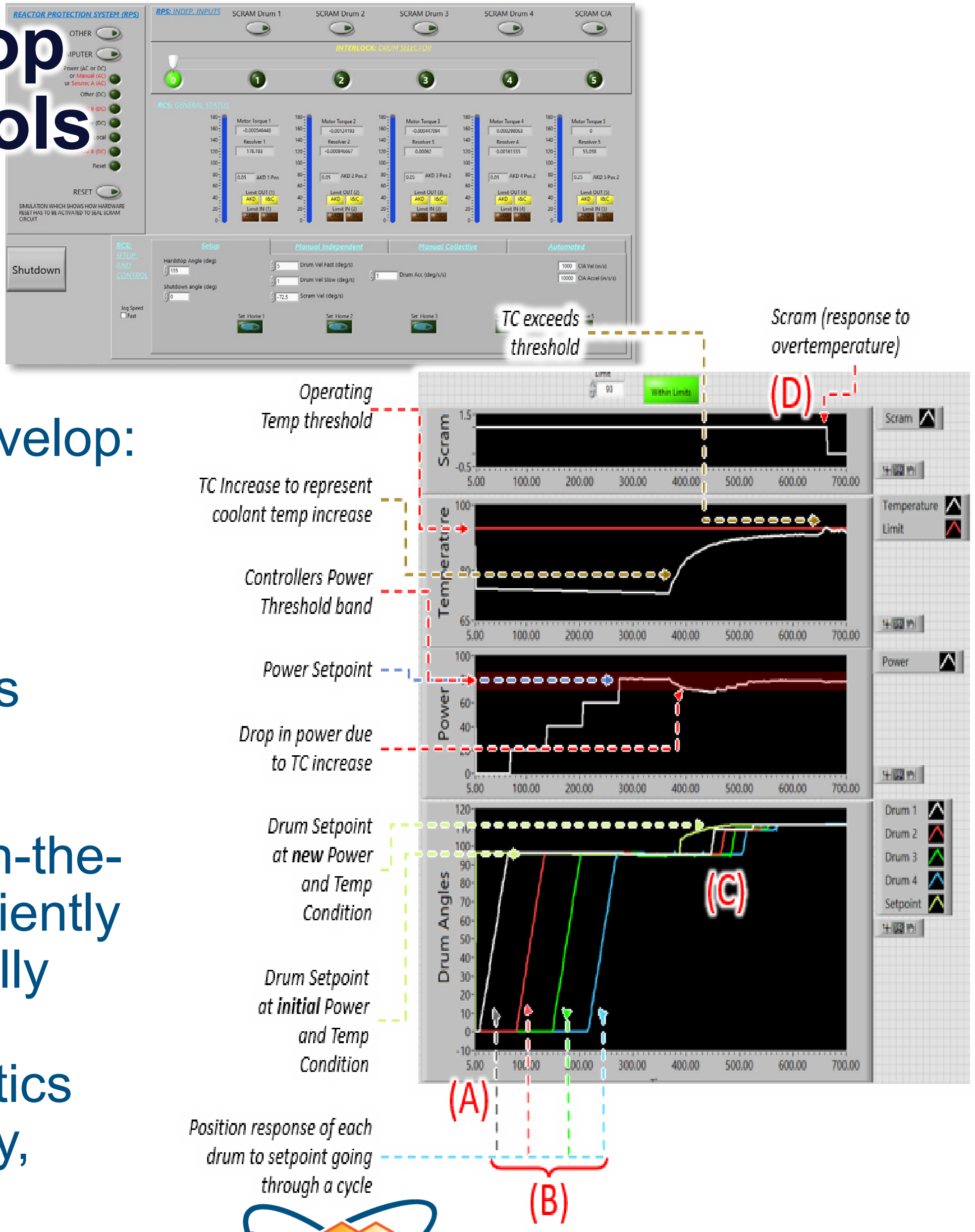
# MRP's MACS Platform used to Develop ASI Digital Twin and Advanced Controls

Applying MACS platform to develop:

- digital twin
- advanced control
- sensor interfacing strategies

*MACS provides a hardware-in-the-loop configuration that is sufficiently flexible to digitally and physically mimic various microreactor configurations and characteristics (e.g. different coolant, reactivity, geometry, etc.).

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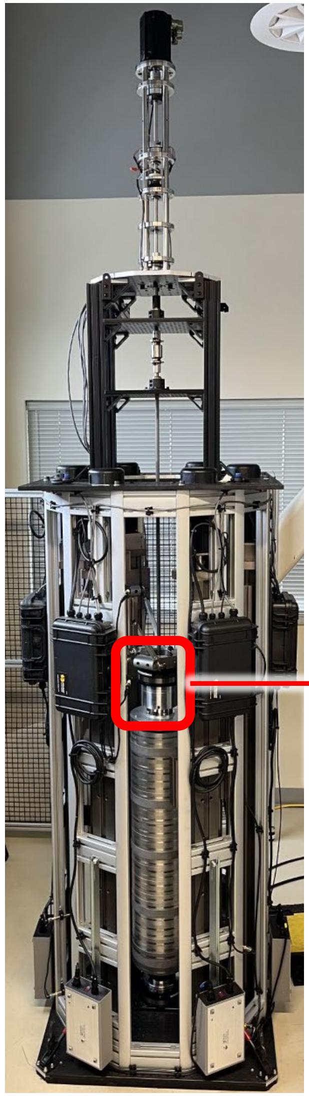
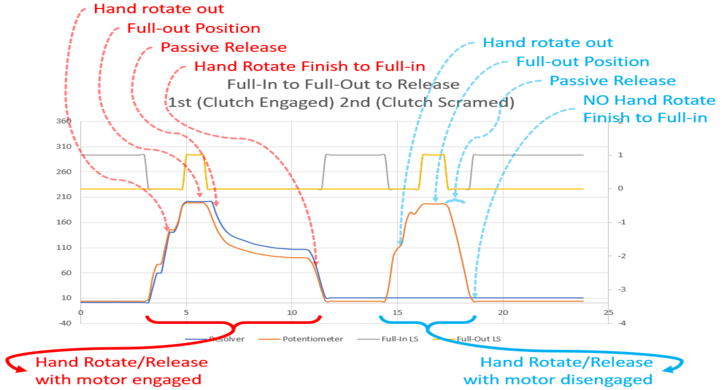
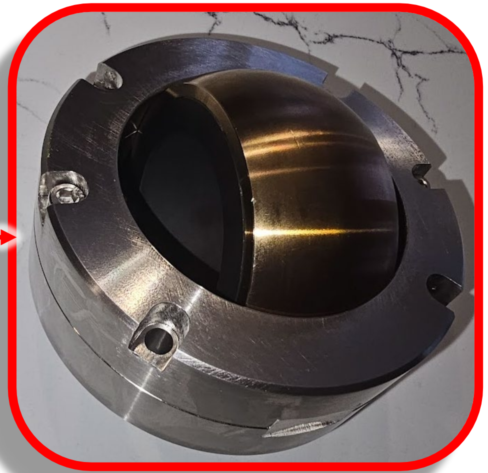
# MRP's MARVEL Control Drum System Testing in ASI Double Delta Structural Analysis System



- Applied the ASI Double Delta to induce deflections commensurate of the expected MARVEL nuclear environment while assessing rotational performance
- Study resulted in a **critical** MARVEL bearing design update




Update from binding sleeve bearing to misalignment accommodating spherical bearing



Updated Housing Design by Peter Ritchie

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# Questions?

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https://gain.inl.gov/SitePages/MicroreactorProgram.aspx

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