FY22 Microreactor Program (MRP) Review

Instrumentation and Sensors

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Objective

- Instrumentation and sensors research falls into three main categories:
  - primary instrumentation for nonnuclear testing,
  - embedded sensors for determining operating parameters, and
  - techniques for determining structural health.
- As part of nonnuclear test bed demonstrations, the program will research techniques for measuring parameters from heat pipes and/or other materials tested.
- Instrumentation technologies to monitor the structural integrity of microreactor structures operating at high temperatures (e.g., > 600°C) are also being developed.

MRP Microreactor Program

Microreactor I&C needs

Today's light water reactors

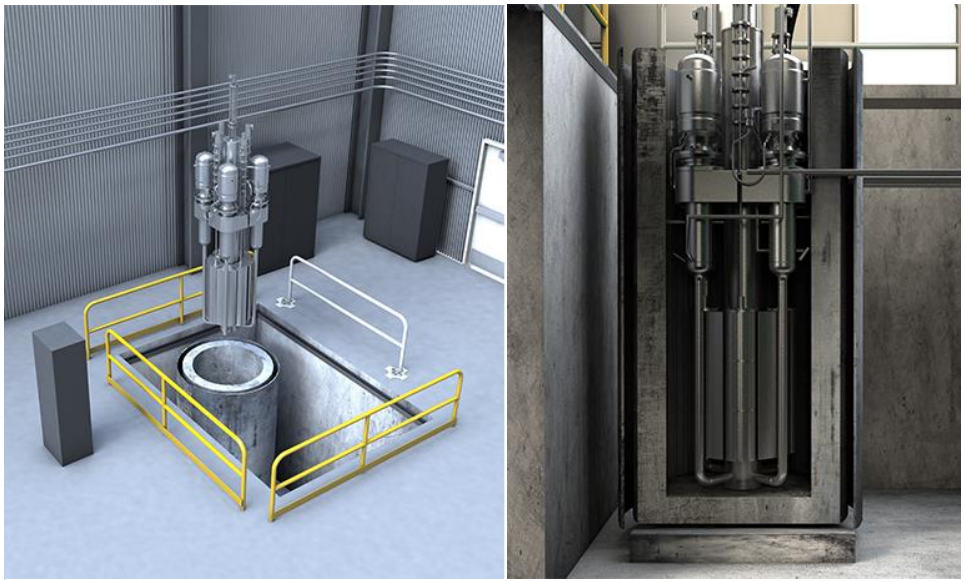
- ~1000 MWe
- Large, onsite construction
- Regular, ~18 month refueling cycles
- ~Hundreds of onsite staff
- Large, expensive redundant safety systems
- Hesitant to adopt new I&C technology

Microreactor concepts

- ~kWe to tens of MWe
- Factory assembly, deployable
  - Instrumentation ideally integrated into factory assembly
- Some reactor concepts are never refueled
  - May enable increasing instrumentation without interfering with refueling operations
- ~Tens of onsite staff
  - Instrumentation must inform limited number of operators
  - Ideally passively safe, could support autonomous operation
- Small footprint limits space for instrumentation

Westinghouse AP1000 plant

https://www.westinghousenuclear.com/new-plants/ap1000-pwr

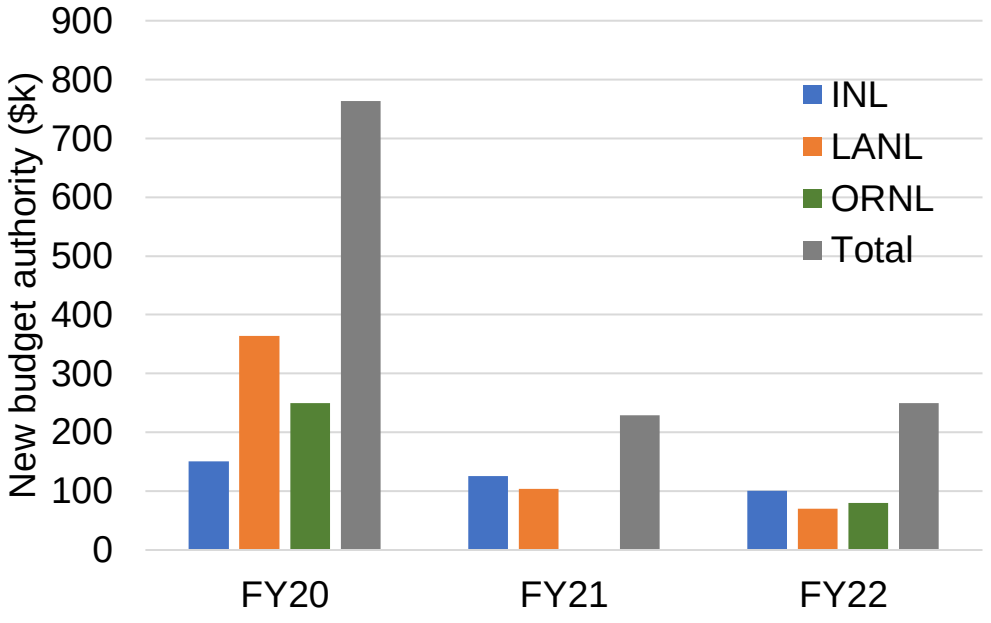


MARVEL microreactor

https://www.energy.gov/sites/default/files/styles/full_article_width/public/2021-04/MARVEL_TREAT_high-res.png?itok=w0WkRoYL

Scope

- Instrumentation and Sensors activities funded at levels that allow simple demonstrations that leverage other MRP-funded or NE-funded activities to maximize productivity

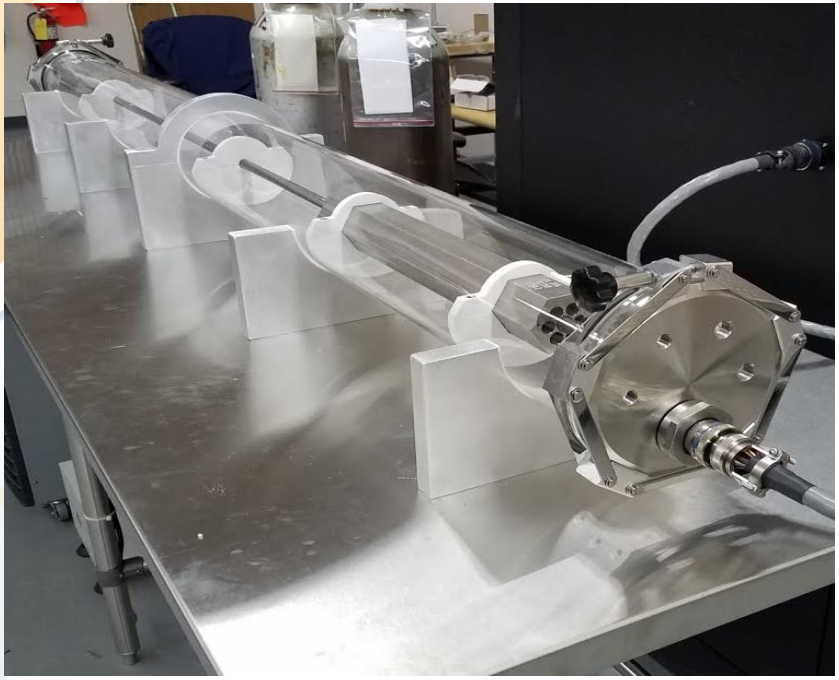


MRP instrumentation & sensors budget history

  - MRP Capability Development: SPHERE, MAGNET testbeds
  - Nuclear Energy Enabling Technologies Advanced Sensors and Instrumentation (NEET ASI) Program: Various sensor development activities
  - Transformational Challenge Reactor (TCR) Program: AM-embedded sensors

- Programmatic focus
  - Health monitoring of microreactor components using embedded sensors, distributed sensors and other advanced sensing technologies during electrically-heated testing in SPHERE and MAGNET
  - Enhanced diagnostics to detect and mitigate issues and prevent unplanned shutdowns for maintenance
  - Advanced control strategies to support semi-autonomous operation

MRP: SPHERE and MAGNET testbeds (INL)



SPHERE - Single Primary Heat Extraction and Removal Emulator

- Single heat pipe coupled to forced convection cooling, surrounded by 6 electrical heaters
- Designed to quantify operational temperatures and heat rejection from of a single heat pipe
- Highly instrumented to measure temperature and strain distributions in a miniature monolithic core block

MAGNET - AGile Non-nuclear Experimental Test Bed

- Engineering scale test bed for testing large sections of a monolithic core block with an array (e.g., 37) of heat pipes and electrical heaters
- Capable of testing advanced heat rejection systems or integral effects such as the potential for cascading failures of multiple heat pipes

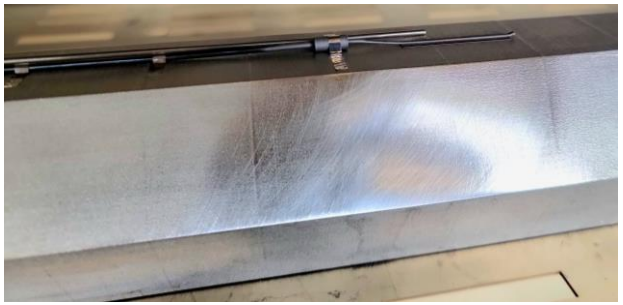
Increasing complexity

MRP Microreactor Program

Leveraging sensor development activities under NEET ASI (INL)

- New website - https://asi.inl.gov/
- Fiber optic multi-point and distributed temperature sensor
  - Quantifying sensor performance and use under specific conditions
- Thermocouples
  - Performance assessment of commercial thermocouples
- Ultrasound thermometers
  - Fabrication optimization for high temperature/radiation environments
- Mechanical Properties
  - Deploy commercial high temperature strain gauges in SPHERE/MAGNET with ORNL developed embedded fiber strain gauge
  - Support Consolidated Innovative Nuclear Research call CT-5 for structural health monitoring of advanced reactors
- More input to Nuclear Energy Sensors Database, https://nes.energy.gov/

Thermocouple installed in SPHERE

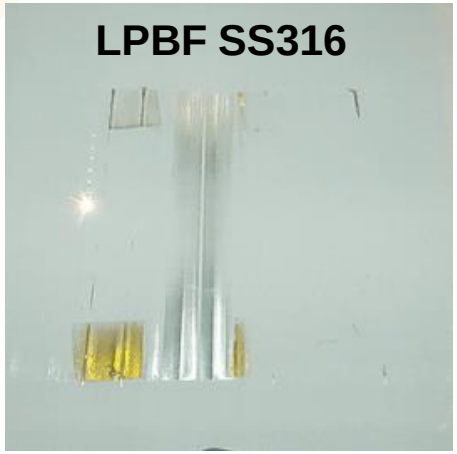


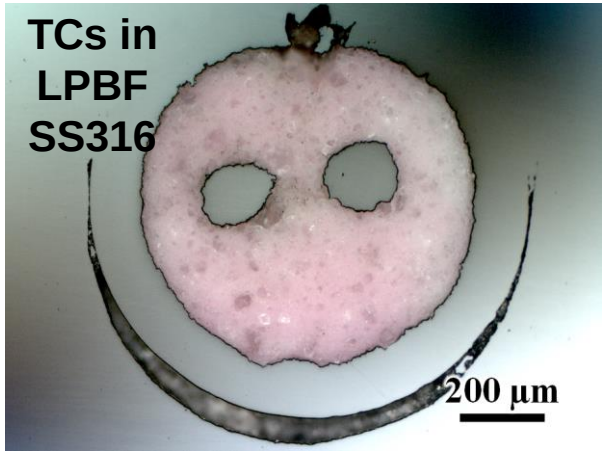
Welded strain gauge on a hexagonal test article for heat pipe-based microreactors

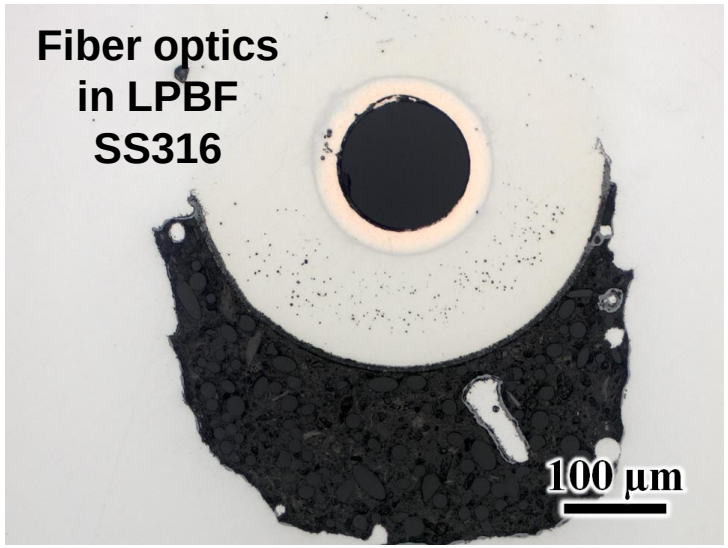
CT-5: ADVANCED SENSORS AND INSTRUMENTATION
FEDERAL POC – DANIEL NICHOLS & TECHNICAL POC – PATTRICK CALDERONI)
(ELIGIBLE TO LEAD: UNIVERSITIES ONLY)
(UP TO 3 YEARS AND $800,000)

The Advanced Sensors and Instrumentation (ASI) program seeks applications to develop dynamic measurement systems for structural health monitoring of advanced reactors. Advanced reactors of interest are those defined in section A.2.2 Reactor Concepts Research, Development and Demonstration (RC RD&D) Program and related items in Appendix A. The proposal should demonstrate an adequate level of knowledge of the targeted application.

Leveraging AM and sensor embedding under TCR (ORNL)





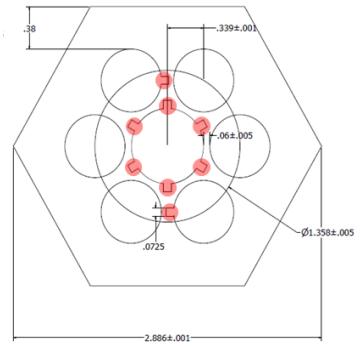


Embedding of fiber optics and thermocouples in stainless steel using ultrasonic additive manufacturing (UAM) and laser powder bed fusion (LPBF)

Embedding of thermocouples in binder jet (BJ) 3D printed SiC + chemical vapor infiltration (CVI)

INL accomplishments: Distributed temperature sensing in SPHERE

- Core block modified to include additional instrumentation
- New SPHERE test stands (horizontal/vertical) allow more room for sensor leads
- Thermocouples: Ordered, vendor delays
- Fiber-optic temperature sensors: Part in-house, under fabrication
- Ultrasound temperature sensor: Fabricated, undergoing heat treatment and calibration
- *Vendor delays caused delay of INL - M4 SPHERE deployment milestone into April*



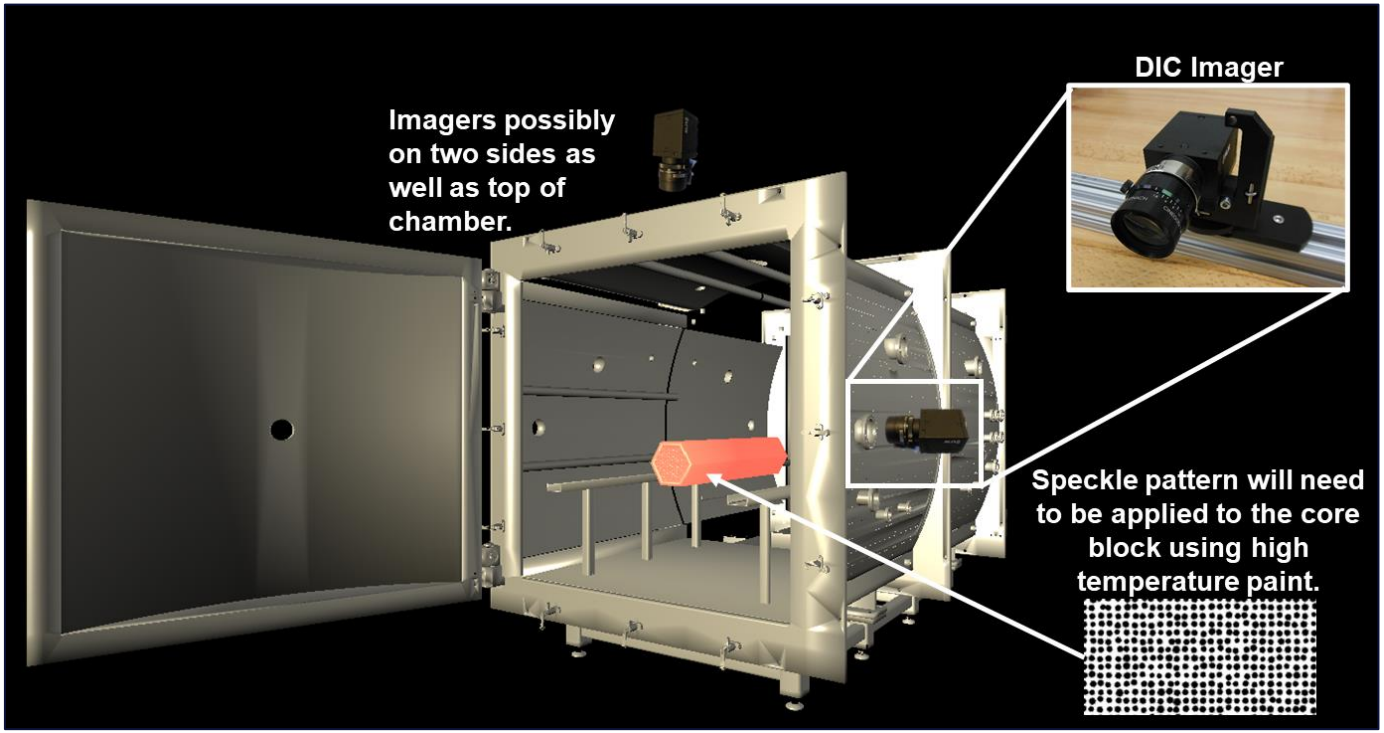
Modified core block with extra channels for instrumentation

Horizontal and vertical test stands at SPHERE

LANL accomplishments: Non-contact digital image correlation (DIC) for MAGNET testing

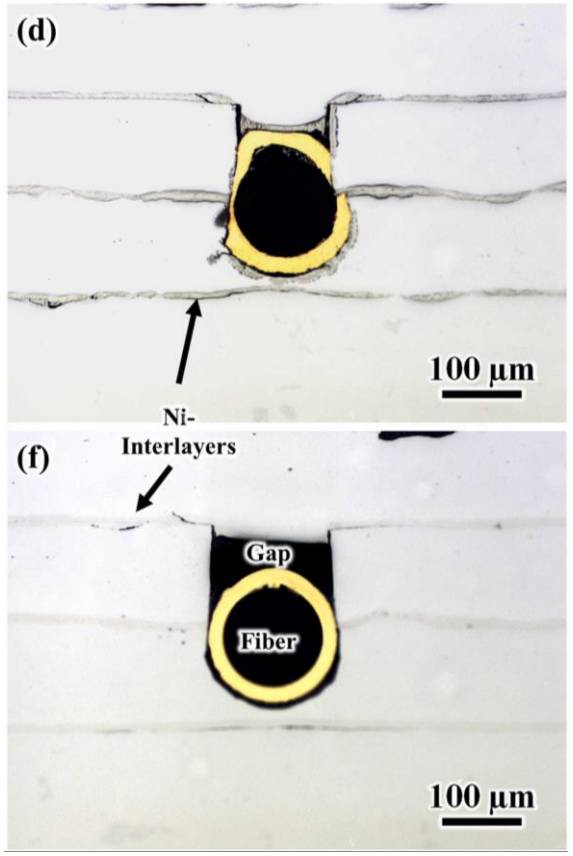
- Simulated the lighting and potential distortion effects due to high temperatures on DIC measurements
- Determined optimum speckle size, focal length, and camera locations in MAGNET
- Currently performing high-temperature tests on 316 SS coupons

MAGNET DIC configuration



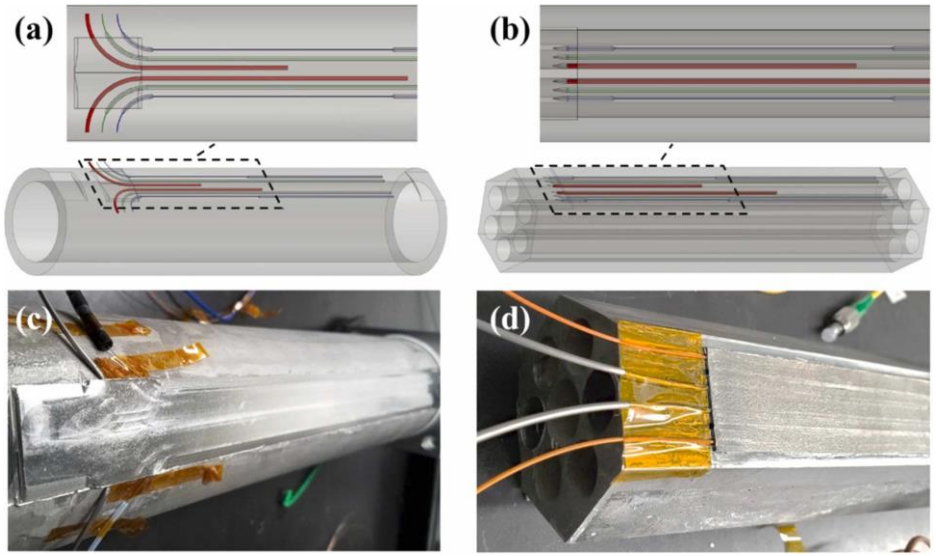
ORNL accomplishments: Demonstration of functional sensors embedded in microreactor components

- FY20–FY21 focused on expanding UAM process to embed thermocouples and fiber optic sensors in pipes and microreactor core block test articles
- Journal manuscript in FY22 on sensor embedding, thermal gradient testing, and characterization of sensor/component interfaces[1]
- Sent test article with embedded thermocouples and fiber optics to INL for testing in SPHERE
- SPHERE testing planned for spring of 2022



Process parameters optimized to achieve fiber optic strain coupling without damaging sensors

Test articles with embedded sensors



[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. https://doi.org/10.1016/j.addma.2022.102681

Milestone status

- **On schedule**
  - **INL, M4AT-22IN0804027:** Test distributed temperature sensors in MAGNET deployment (due 7/28/22)
  - **INL, M3AT-IN0804028:** Prepare report to document sensors and instrumentation (due 8/31/22)
  - **ORNL, M3AT-22OR0804011:** Deliver test article with embedded sensors to INL and test performance (due 7/29/22)
  - **LANL, M4AT-22LA0804031:** Report on proposed structural health measurements at MAGNET (due 9/30/22)
- **Delayed**
  - **INL, M4AT-22IN0804026:** Test distributed temperature sensors in SPHERE deployment (originally due 12/31/21)
    - Delayed until 4/26/22 due to vendor delays in delivering thermocouples

MRP Microreactor Program

Conclusions

- This work packages supports a wide range of technology maturation activities centered around instrumentation and sensors
  - Improved monitoring capabilities during nuclear and non-nuclear testing of microreactor components and systems
  - Health monitoring of operating microreactors using advanced non-contact and embedding sensing technologies
- FY21 focused on fabrication and initial testing of sensor technologies and embedding techniques
- FY22 is focused on:
  - Demonstrating these technologies during non-nuclear testing of microreactor components
  - Evaluation of options for structural health monitoring of larger components in MAGNET
- Potential FY23 scope includes:
  - Health monitoring/damage detection in microreactor components
  - Deploying distributed sensing technologies in the MAGNET testbed
  - Automated control and/or acoustic sensing

MRP Microreactor Program