DOE-NE Microreactor Program Winter Review Meeting

Technology Maturation

Technical Area Lead: Holly Trellue

Los Alamos National Laboratory

March 5, 2025

Synergistic Development of Microreactor Technology

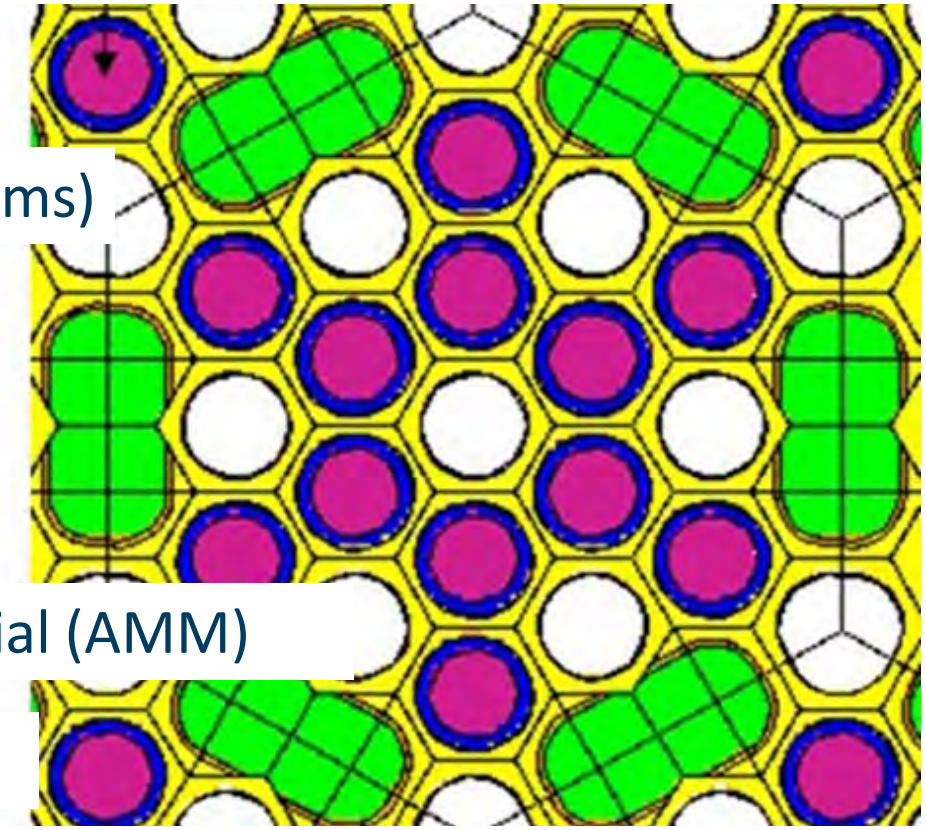
Fuel (other programs)

Moderator

Heat Transfer
(e.g. Heat pipes)

'Structural' Material (AMM)

Instrumentation & Sensors



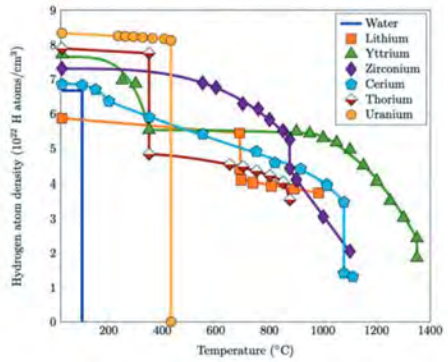
MRP Microreactor Program

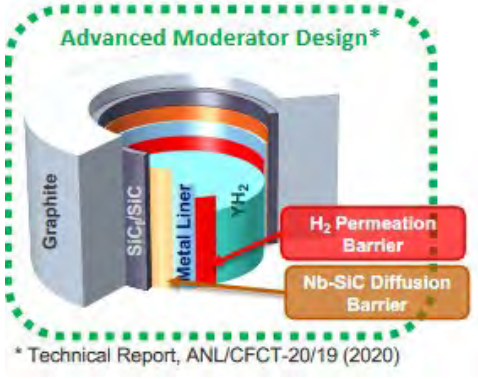
How Technology Maturation Meets Program Objectives

- Through cross-cutting research and development and technology demonstration support, achieve technological breakthroughs for key features of microreactors, examine:
  - Moderation to reduce required fuel mass
  - Microreactor Automated Control System to move control material in response to reactivity changes
  - Advanced heat transfer to remove heat from a microreactor core
- Meet critical R&D needs of existing developers that require national lab or university expertise or capabilities.
  - Develop containment mechanism to keep hydrogen within moderating material for reactivity purposes
  - Design state-of-the-art heat exchangers to transfer heat from the core to thermal energy or power production
  - Build and test non-nuclear test articles
- Develop advanced technologies and concepts for next-generation microreactor applications and systems.
  - Design and test state-of-the-art technology for the above
  - Understand structural health concerns and performance of systems using instrumentation
- Enable future microreactor applications through:
  - Coupling of the above components
  - Developing technology that vendors can eventually use

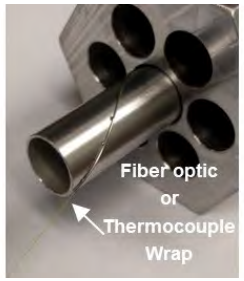
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THREE control areas ACTIVEly supported



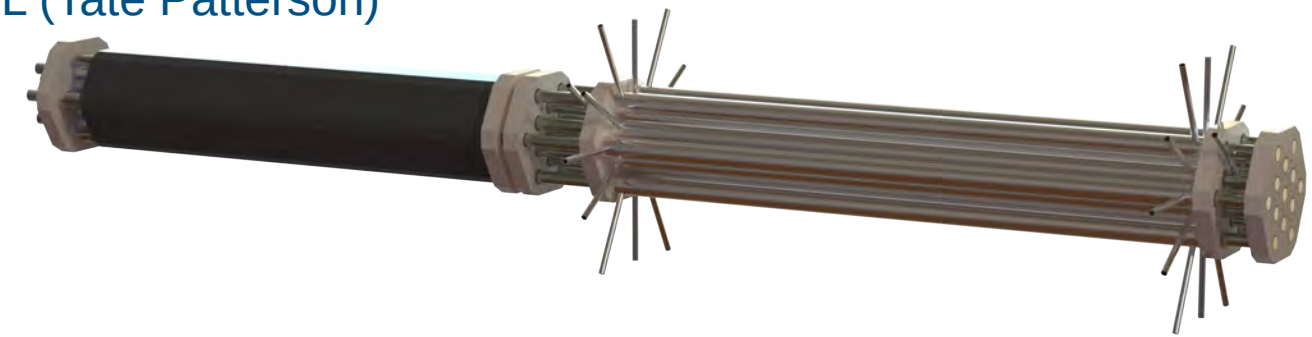


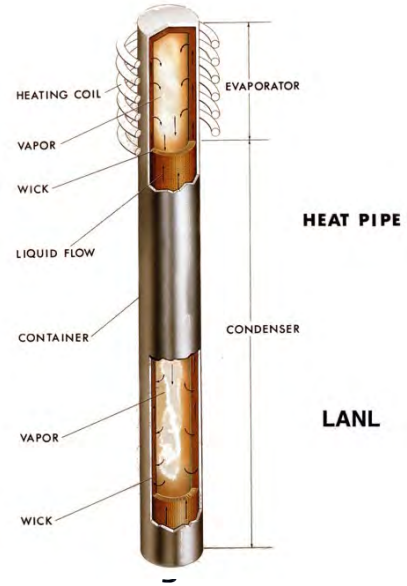
- High Temperature Moderator Material – yttrium hydride (YH)
  - LANL (Caitlin Kohnert)
  - ANL (Latif Yacout)
  - ORNL (Kory Linton)
- Instrumentation and Sensors – Microreactor Automated Control System and structural health
  - INL (Tony Crawford)
  - ORNL (Chris Petrie/
  - Pradeep Ramuhalli)
  - LANL (Paul Geimer)



(Focused on stainless last two years, now looking at graphite)

- Heat Transfer – individual heat pipe and larger test article generation
  - LANL (Katrina Sweetland)
- Structural Material is now overseen by the Advanced Manufacturing Material Program
  - INL (Tate Patterson)



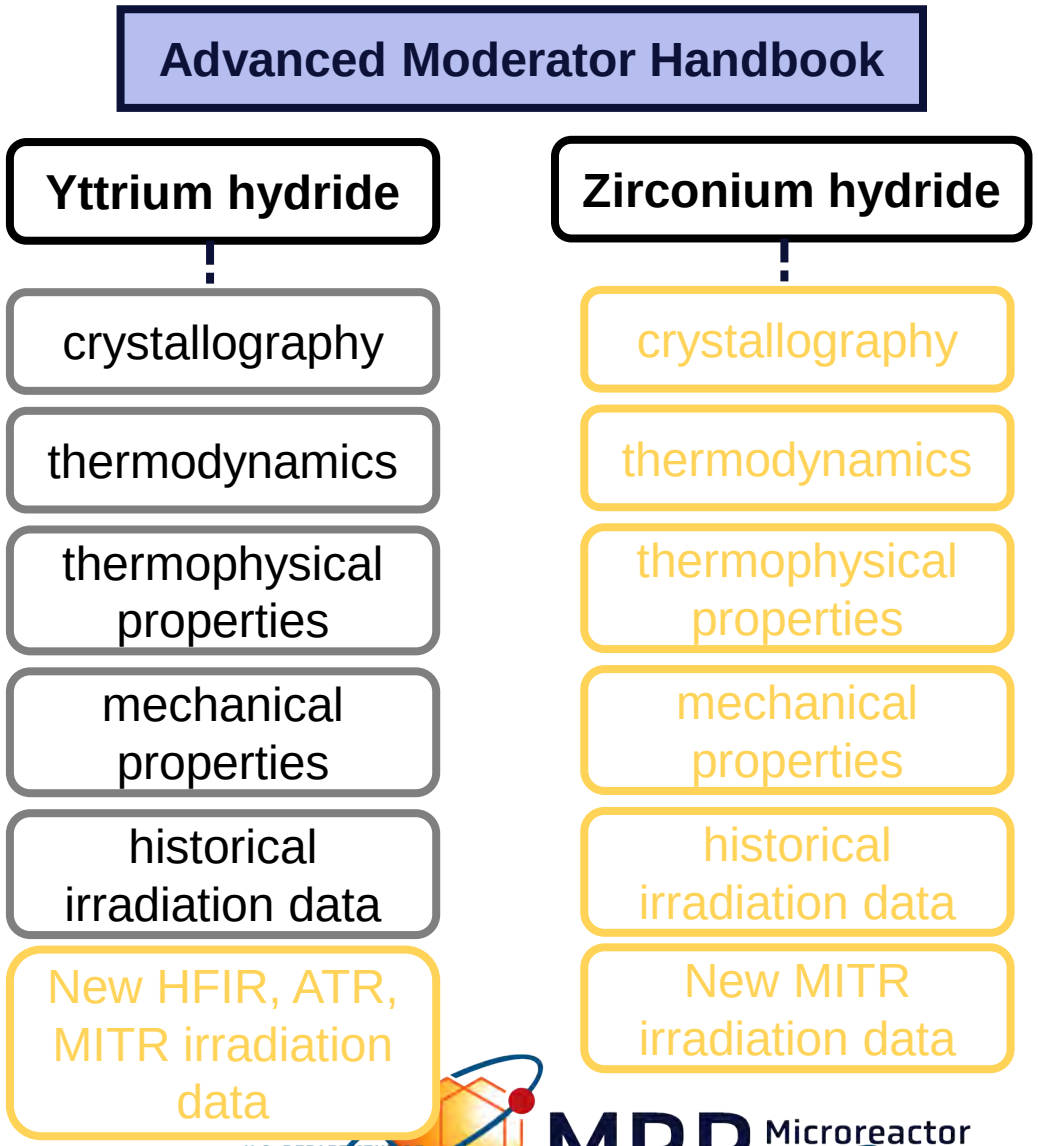


Outline

- 8:05 - 8:20 Technology Maturation Overview **Holly Trellue**
- 8:20 – 8:45 High Temperature Moderator Containment **Sumit Bhattacharya/Latif Yacout**
- 8:45 – 9:05 Analysis of HFIR irradiated YH **Nedim Cinbiz/Kory Linton**
- 9:05 – 9:25 Instrumentation and Sensors – Microreactor Automatic Control System (MACS) Hardware in the Loop **Tony Crawford**
- 9:25 – 9:45 Instrumentation and Sensors – Microreactor Automatic Control System (MACS) Software Development **Pradeep Ramuhali/Jono McCo**
- 9:45 – 10:05 Instrumentation and Sensors – Acoustics in graphite **Paul Geimer**
- 10:05 – 10:25 Instrumentation and Sensors – Conductivity in graphite **Chris Petrie**
- 11:00 – 11:20 Graphite Test Article and heat pipes (Heat Transfer) **Martin Ward/Katrina Sweetland**
- 11:20 – 11:40 Structural Materials - PM-HIP code case **Tate Patterson**
- 11:40 – 11:50 Wrap Up Technology Maturation/Critical Experiments **Holly Trellue**

Advanced Moderator Handbook produced by LANL is being enhanced

- The goal of the Handbook is to provide scientists and reactor designers with a set of physical and thermal property data for metal hydride moderators.
- Topics included are summarized in the flow chart to the right.
- Critical experiment nuclear data/S(a,b) verifications for YH.
- Post-irradiation examination performance.



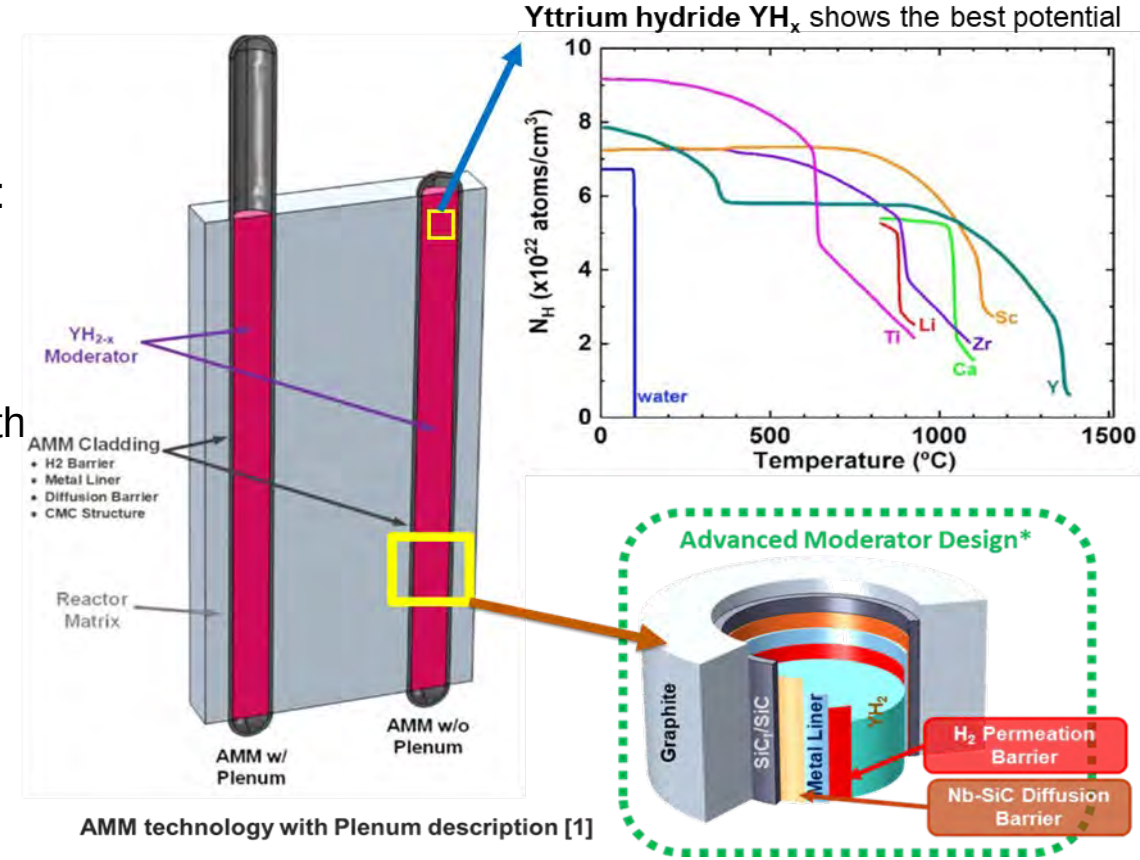
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ADVANCED MODERATOR MODULE (AMM) CONCEPT

Objective: Argonne National Laboratory is developing an AMM featuring a YH_{2-x} metal hydride, encased in a niobium (Nb) liner with a permeation barrier to contain hydrogen at high temperatures, and a silicon carbide (SiC) composite cladding for structural integrity.

Advantages of the AMM design:

- Utilizing metal hydrides, like YH_{2-x}, allows optimal moderation
- AMM's encapsulation method promises improved performance:
  - Improved H_2 retention.
  - Reduced thermal neutron absorption compared to other approaches (e.g., SS, high temp. alloys, ..).
  - Successful deployment will support small microreactor cores with extended operational lifetimes.



AMM technology with Plenum description [1]

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Advanced test Reactor Post-Irradiation Examination Activities at INL several years ago

1- Geometrical and structural stability

- Neutron radiography, visual examination of assemblies, capsules, and samples
- Metallography and electron microscopy of yttrium hydride

2- Predictable behavior

Assessment of hydrogen behavior/content

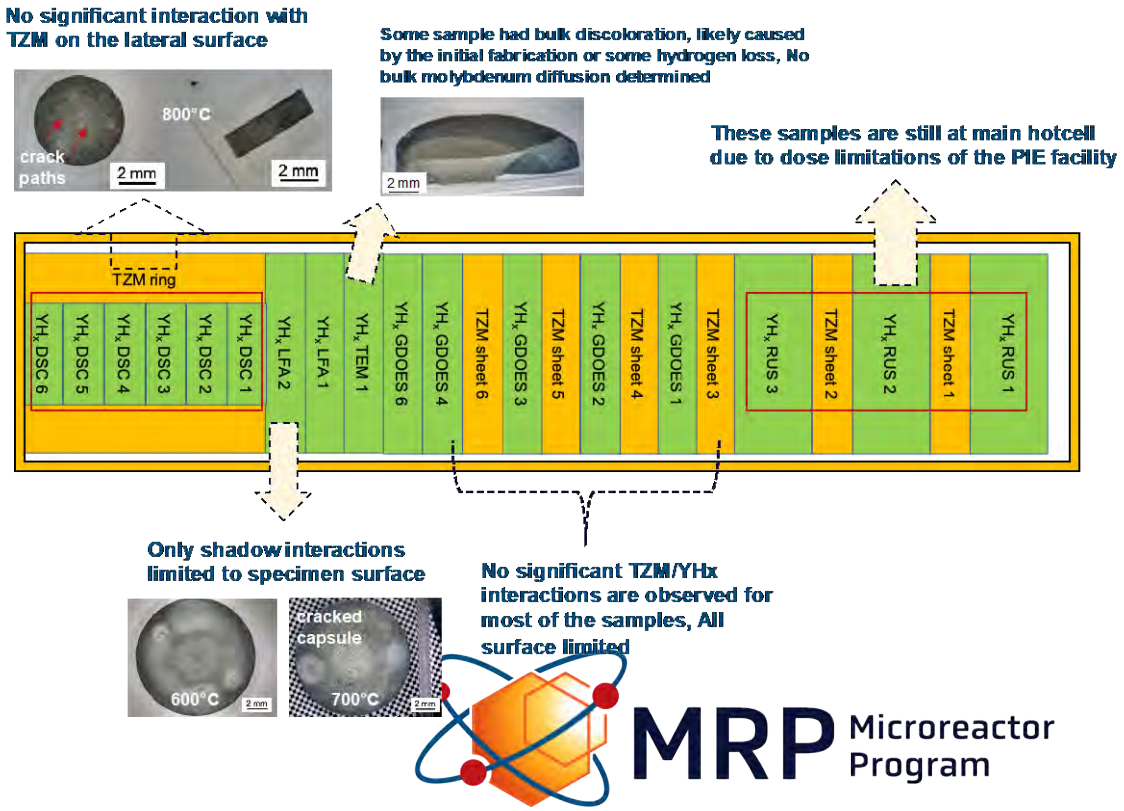
- Hydrogen content measurement to assess hydrogen content
- X-ray diffraction measurements to assess hydride and metal phases

Thermal properties

- Thermal diffusivity and heat capacity investigations
- Dilatometry for thermal expansion measurements were not included in the PIE due to dose limitations of the facilities

Major goal is to determine a hydrogen assessment metric for irradiated yttrium hydride

- ***Samples | 102 yttrium hydride specimens | 36 TZM foils***
- ***Two fabrication paths | Direct hydriding and Powder metallurgy***
- ***Target temperatures | 600, 700, and 800˚C***
- ***Irradiation conditions | 60 full power days***

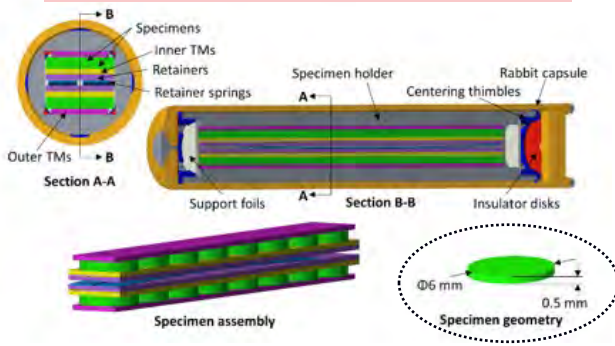


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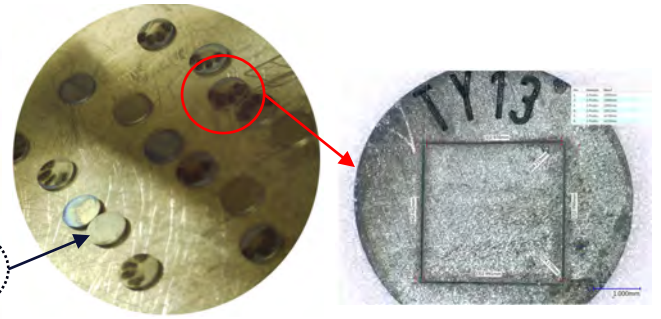
Assessing Hydrogen Retention in Hydride Moderators at ORNL from High Flux Isotope Reactor (HFIR)

- Hydrogen retention is a key parameter for hydride moderators in microreactors, including self-moderating hydride-fueled microreactors like INL's pioneering MARVEL demonstration reactor.
- High hydrogen mobility in the moderator makes retention assessment challenging.

HFIR Irradiation Design

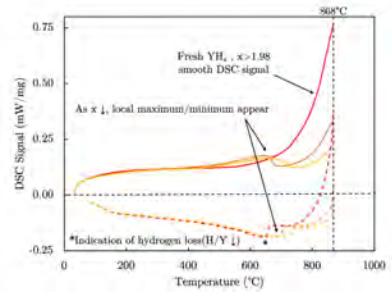


Post Irradiation Disassembly



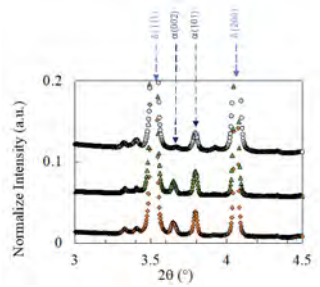
Investigation Approach on HFIR Irradiated Samples:

Thermal property measurements



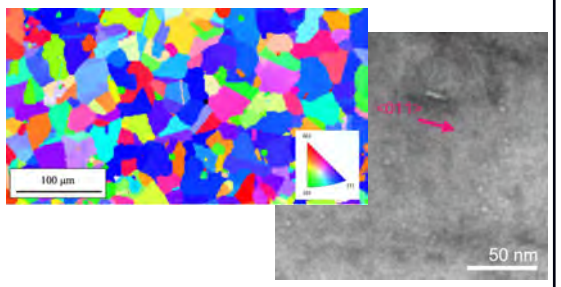
Differential Scanning Calorimetry - Measuring thermal property variations to assess hydrogen-to-metal ratio changes.

High-Energy X-Ray Diffraction



XRD - Determining hydride-to-metal phase ratios, a direct hydrogen retention metric.

Microstructure Characterization



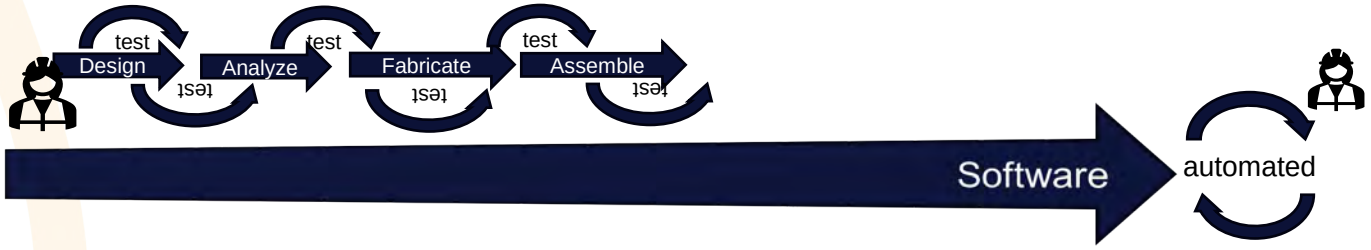
SEM-EBSD/TEM - Identifying structural features like cavities that influence hydrogen retention.

ORNL's post-irradiation examination (PIE) aims to develop robust hydrogen retention metrics, supporting the technology maturation phase of the microreactor program.

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

- **A robust, adaptable, interchangeable, hardware in the loop control platform that enables graded automation**
- Mature Microreactor control technologies to pave 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 sensor, selection
  - Communication architectures and
  - Optimize placement



MACS/ViBRANT's agile development and reactor surrogate processes produce high quality project faster



Visual Benign Reactor as Analog for Nuclear Testing (ViBRANT) is used as an example

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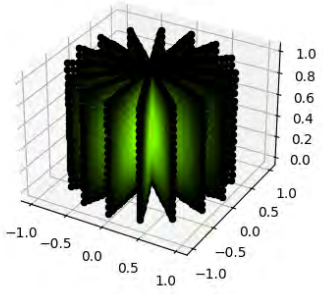
Digital twin Objective and scope

- A robust, high fidelity and adaptable control system that integrates digital twin models and enables graded automation

Scope:

- Integrate microreactor plant-level model with hardware-in-the-loop (HIL) to create a digital twin, leveraging data from representative surrogate hardware systems
- Deliver control algorithms that demonstrate automation at different levels to enable
  - Autonomous operation
  - Remote operation
  - Increased reliability
  - Safety and security of operations

- MACS helps advance microreactor controls technology by enabling
  - Automating recovery from component failures
  - Automation for operational efficiency and cost-competitiveness

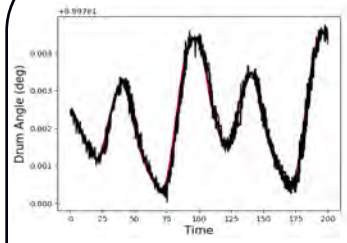


Power Density Distribution Data

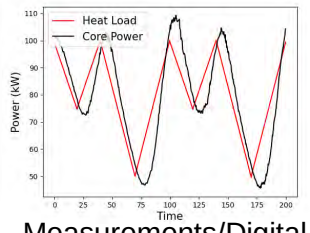


ViBRANT

Hardware-in-the-Loop



Drum Control



Measurements/Digital Twin Simulations

Hardware-in-Loop Control

Digital Twin Model

