INL/MIS-21-62483-Revision-0

Evaluation Plan of Internal and External Senor Technologies for Demonstration in MAGNET

April 2021

Troy Unruh, David Mascarenas , Chris Petrie

Changing the World's Energy Future

Idaho National Laboratory

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Evaluation Plan of Internal and External Sensor Technologies for Demonstration in MAGNET

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Idaho National Laboratory | Oak Ridge National Laboratory | MRP Microreactor Program | Los Alamos National Laboratory | Argonne National Laboratory

Microreactor Instrumentation Overview

- **Scope overview** – Instrumentation is a unique challenge in that technology must be placed in advance to "see" what happens inside a microreactor throughout its life with little or no access.

- **Focus areas include:**
  - Nuclear Energy Enabling Technologies Advanced Sensors and Instrumentation (NEET ASI) program leveraged for demonstration of ASI-developed instrumentation in SPHERE* and MAGNET** (e.g. sensors for nonnuclear tests) lead by INL
  - Sensors for structural health monitoring lead by LANL
  - Embedded sensor development and deployment lead by ORNL

- **Alignment with program objectives**
  - Research and deployment of infrastructure to support demonstration
  - Evaluations aligned with test plan demonstrations outlined in LA-UR-20-20824

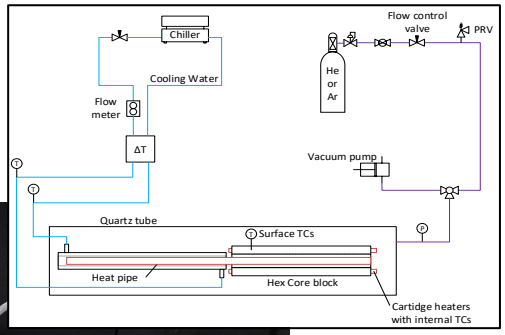
* SPHERE - Single Primary Heat Extraction and Removal Emulator

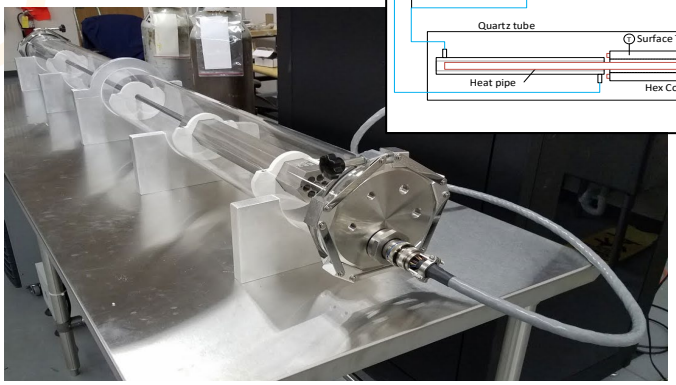
** MAGNET - AGile Non-nuclear Experimental Test Bed

MRP Microreactor Program

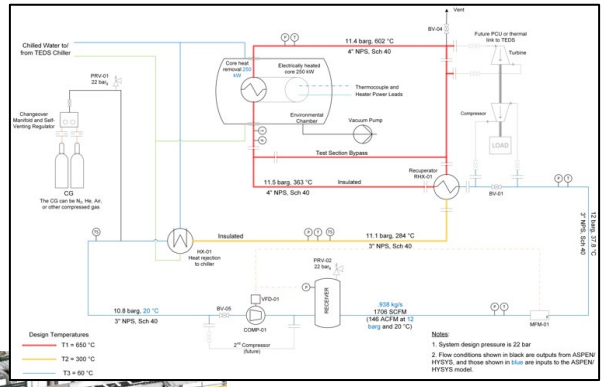
SPHERE to MAGNET – a staged approached to instrumentation and sensor demonstration

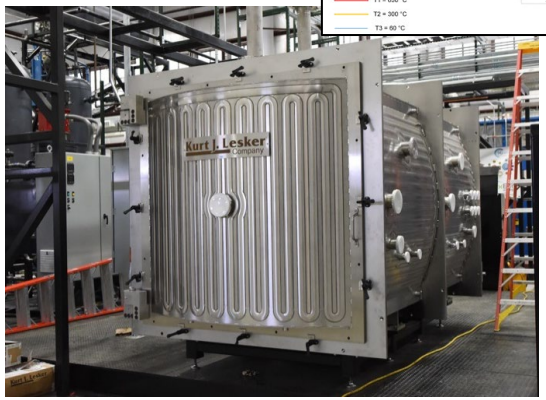
- Instrumentation and sensor demonstration will follow the path to a staged demonstration by leveraging SPHERE and MAGNET where applicable





SPHERE - Single Primary Heat Extraction and Removal Emulator





MAGNET - AGile Non-nuclear Experimental Test Bed

Demonstration complexity increases from SPHERE to MAGNET

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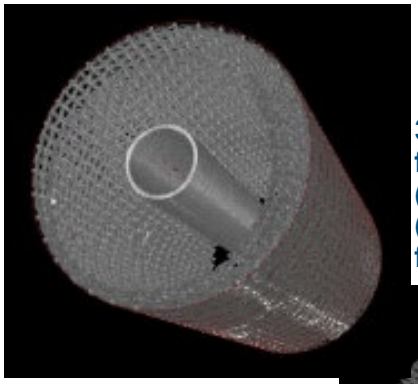
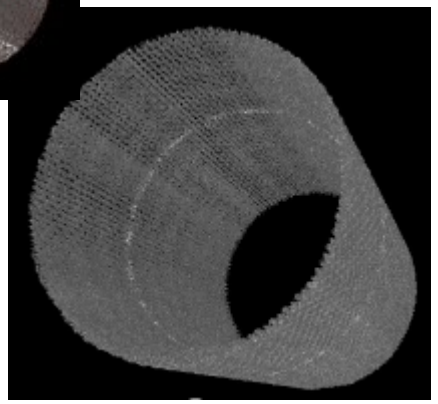
Internal heat pipe temperature measurements for sensor demonstration

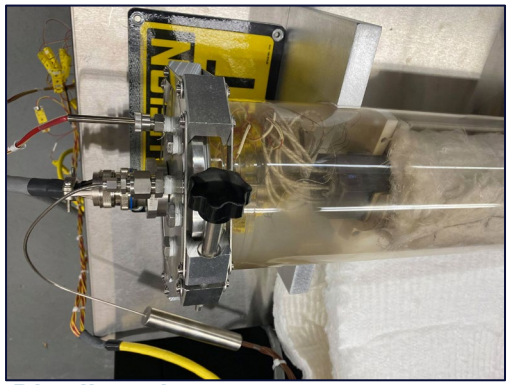
- Two commercial 78.75” long 0.625” OD sodium-filled heat pipes available
  - Include 78.5” long, 0.125” ID thermowell for instrument and sensor demonstration

Thermowell (0.125” ID) in sodium filled heat pipe (0.625” OD) for distributed temperature sensor deployment





3D CT scans of sodium filled heat pipes with (left) and without (below) thermowells for instrument testing



Distributed temperature sensor deployment in heat pipe in SPHERE

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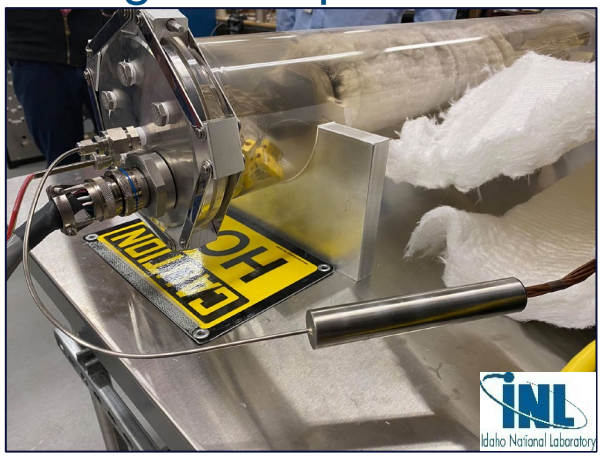
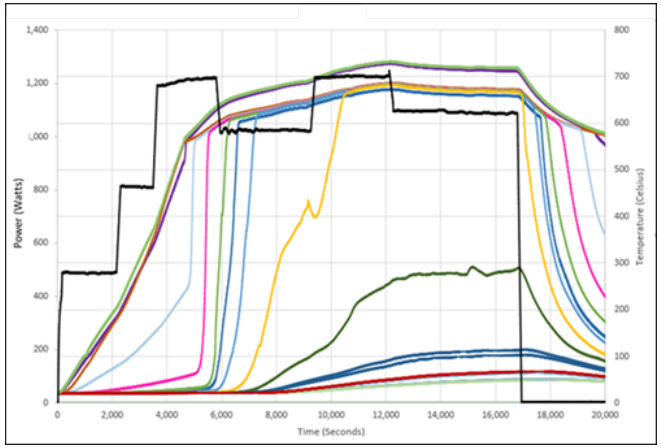
Distributed Temperature Sensors – Thermocouple

- 10-point K-type thermocouple successfully demonstrated for measuring internal heat pipe temperature in SPHERE startup
  - Distributed high temperature irradiation resistant thermocouple will not be deployed in SPHERE or MAGNET due to fabrication delays
- Deployment planned for heat pipe thermowell, in heat pipe to core block gap, tack-welded outside of core block, heat exchanger and power conversion unit



Thermocouple installed in SPHERE

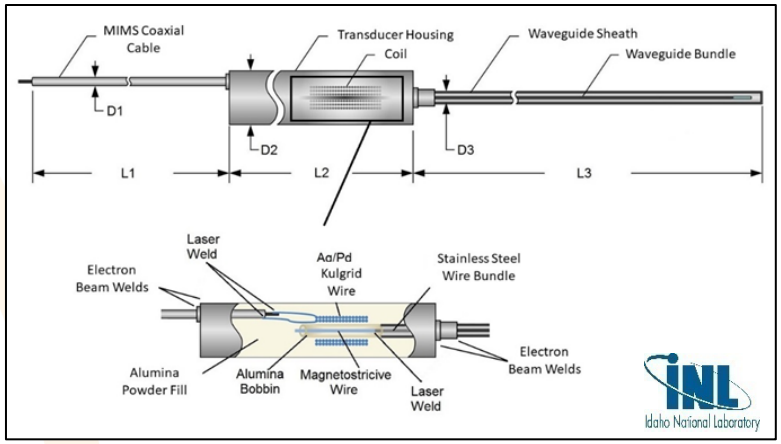


10-point Thermocouple testing in SPHERE

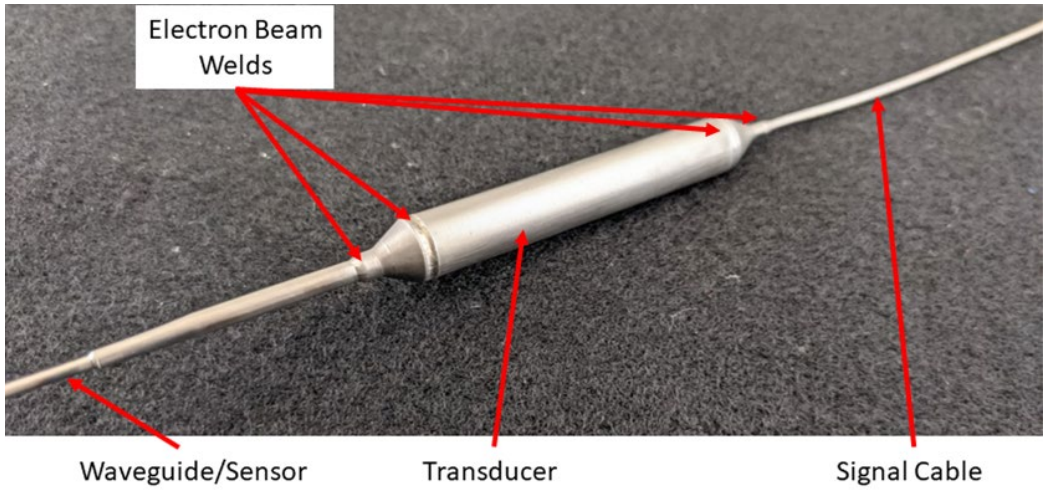
MRP Microreactor Program

Distributed Temperature Sensors – Ultrasonic thermocouple

- Distributed temperature derived from time delay between acoustic echoes of waveguides
- 0.084" OD with 8 waveguide bundle (7 sections)
- Deployment planned for heat pipe thermowell, tack-welded outside of core block, heat exchanger and power conversion unit



Ultrasonic Thermocouple Diagram



Fabricated Ultrasonic Thermocouple

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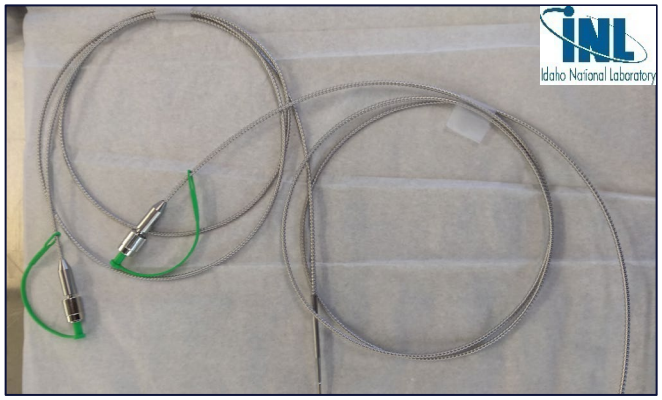
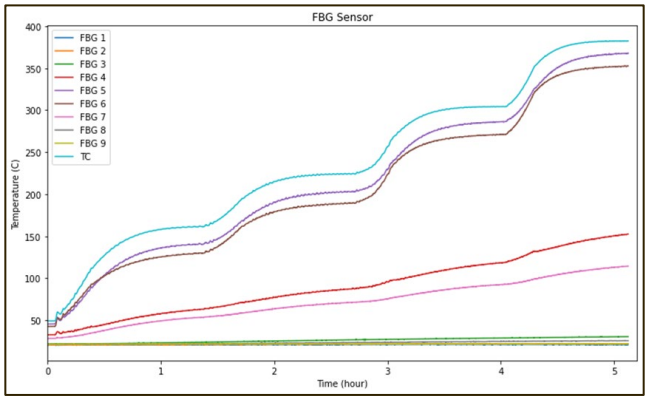
Distributed Temperature Sensors – Fiber optic

- Distributed temperature sensing based on Rayleigh Scattering in optical fibers will provide temperature measurements every centimeter along the entire length of the optical sensor
- Higher temperatures will use a fiber Bragg grating optical fiber with a 9-point Type-II fiber bragg grating (FBG)
- Deployment planned for heat pipe thermowell, in heat pipe to core block gap, tack-welded outside of core block, heat exchanger and power conversion unit



FBG sensor as fabricated



9-point FBG testing

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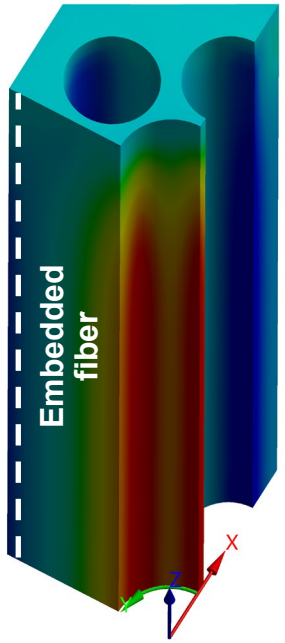
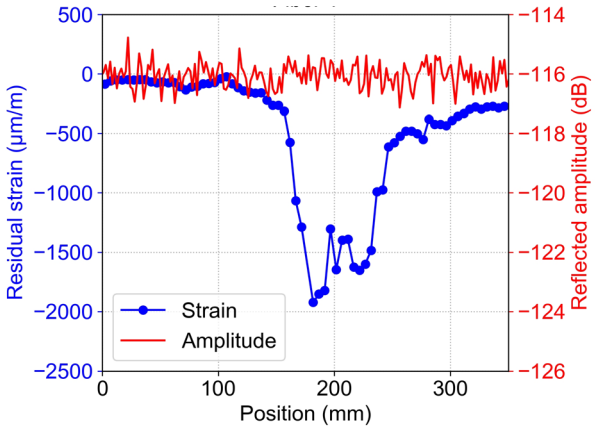
Embedded Sensors – Fiber optic based and thermocouples

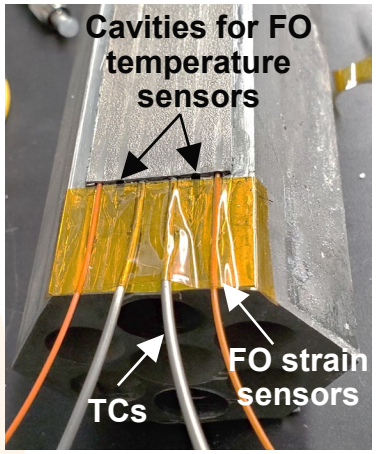
- Spatially-distributed fiber-optic (FO) temperature and strain sensors and thermocouples (TCs) embedded in pipes and core blocks using ultrasonic additive manufacturing (UAM)
  - 1st embedding of fiber-optics in stainless steel successful
- Deployment of embedded sensor core block planned for SPHERE and MAGNET testing



Simulated stress in core block and embedded sensors during single heat pipe testing



Post-embedding FO residual strain and reflected signal



Core block with embedded sensors

Sensor embedding using UAM

From ORNL/SPR-2020/1742

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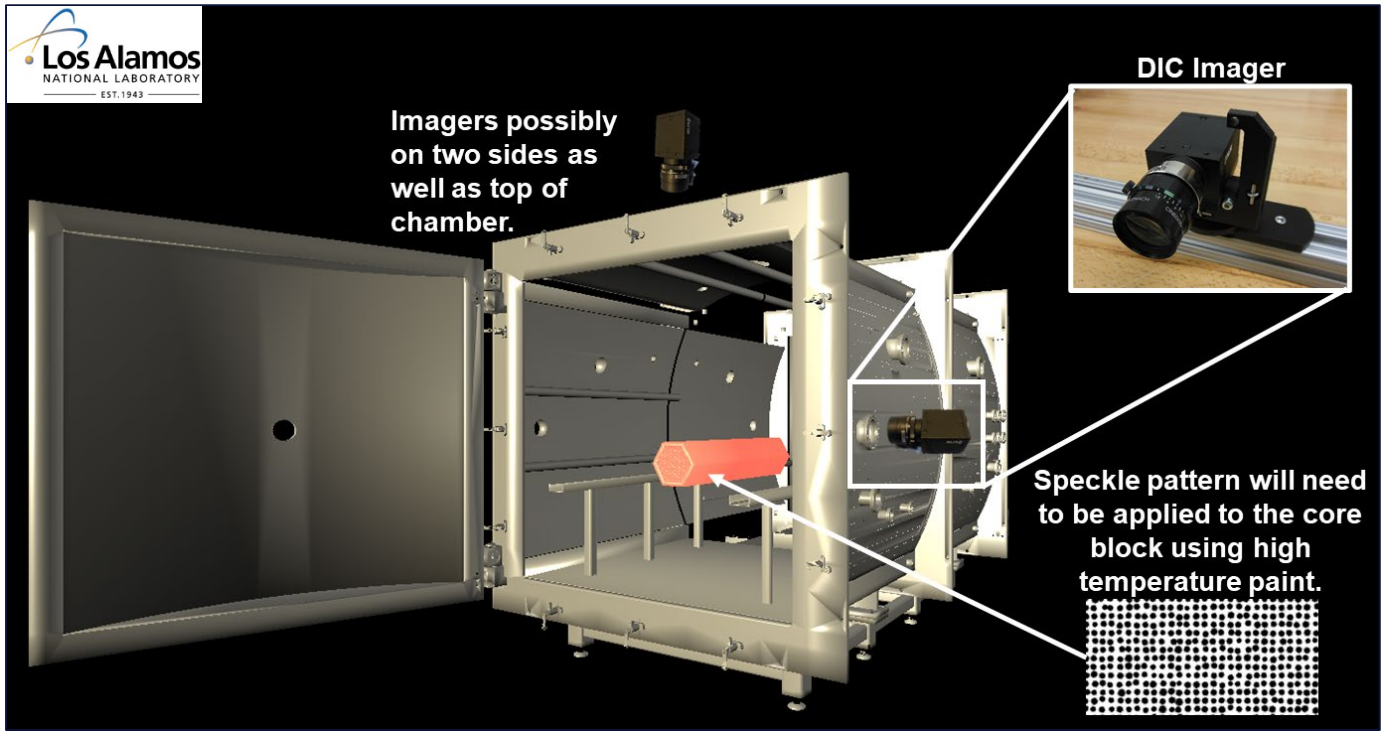
Non-contact sensors – Digital image correlation

- Digital image correlation (DIC) is a very attractive technique for measuring strain and deformation at high spatial resolution as a non-contact, imager-based technique that can potentially be used to measure strain/deformation in 2D or 3D



MAGNET DIC configuration

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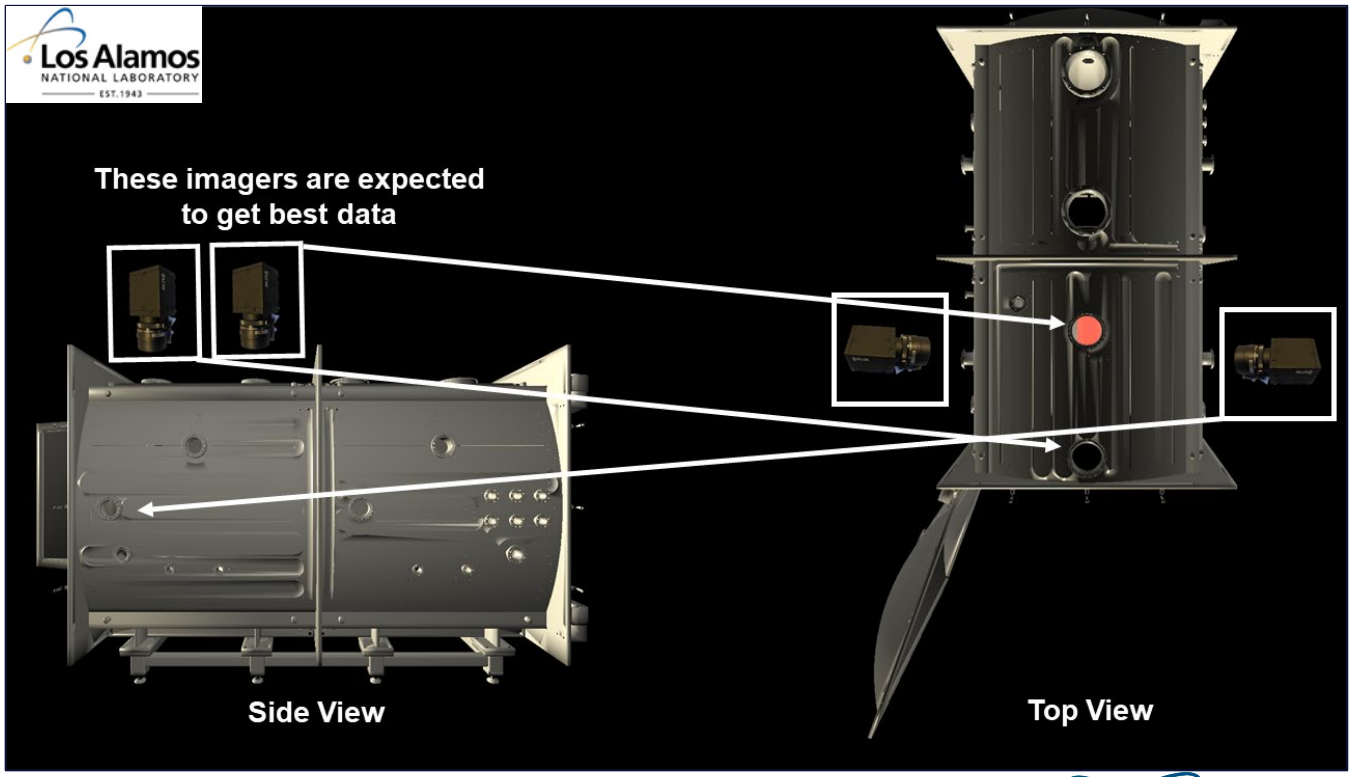
Non-contact sensors – DIC imager locations in MAGNET

- Thermal insulation in SPHERE limits DIC usage
- MAGNET is the planned facility for DIC deployment



MAGNET DIC configuration

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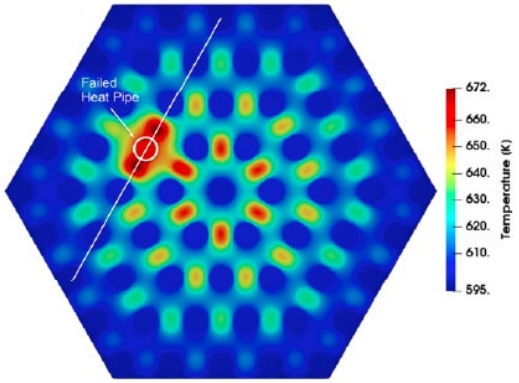
Measurement the thermal changes that result from a failed heat pipe

- Heat pipe-based reactors require experimental testing to quantify heat rejection limitations of heat pipes and thermal stresses in monolithic core blocks
  - Requires detailed mapping of temperature and strain during controlled experiments
- Thermocouples, ultrasonics, fiber optics, embedded sensors, and DIC planned for deployment in MAGNET during a failed heat pipe test and cross-referenced against each other
- Instrumentation will be deployed around failed heat pipe
  - Core block
  - Heat pipe gaps
  - Imaging via DIC
  - Adjacent heaters



Failed heat pipe simulation from LA-UR-20-23798

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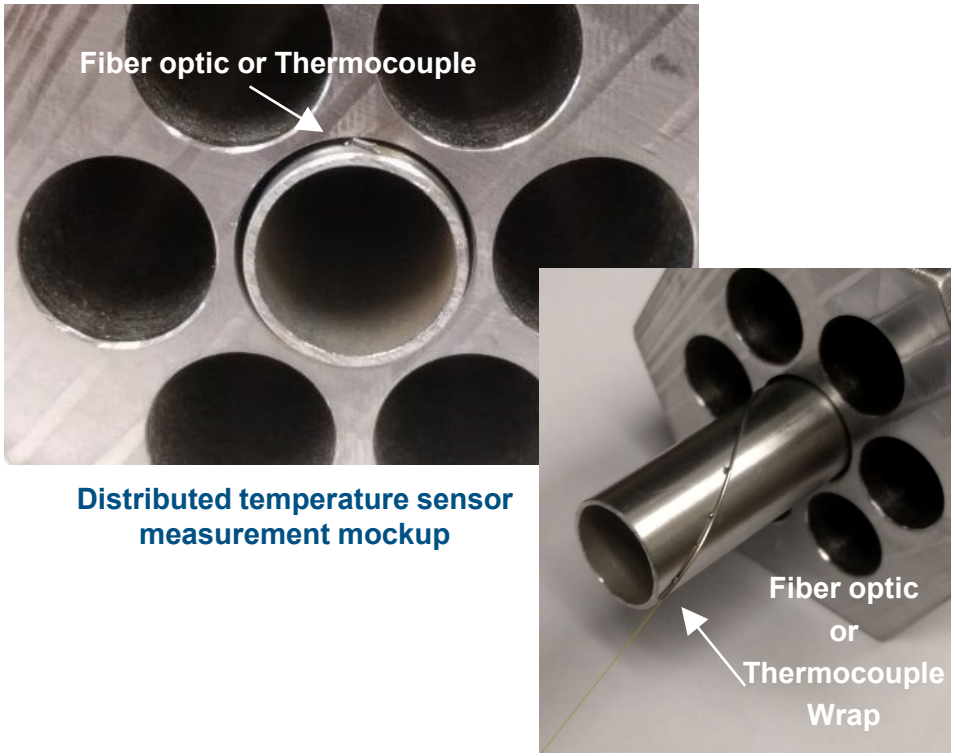
Heat Pipe Gap Measurement – Fiber optics and thermocouples

- Temperature measurement in heat pipe to core block gap
  - Multiple 1/16” thermocouples welded to heat pipe
  - 1/16” distributed fiber optic temperature sensor wrapped and welded to heat pipe
- Measurement deployment planned in SPHERE and MAGNET



Distributed temperature sensor measurement mockup

Thermocouple weld mockup

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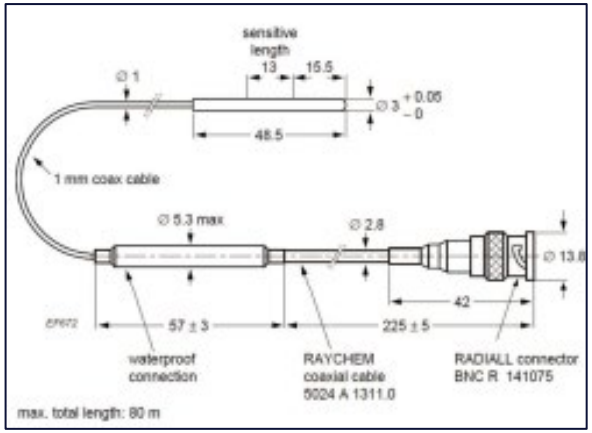
Neutron Flux Sensors – Self-powered neutron detectors and fission chambers

- Self-Powered Neutron Detectors (SPNDs) will be tested in MAGNET to determine thermal response characteristics and to evaluate electrical noise
  - Neutron response testing will be performed in heated Neutron RADiography (NRAD) reactor experiment as part of NEET ASI flux sensor work scope
  - Commercial fission chambers will only be evaluated in heated NRAD experiment as part of NEET ASI sensor work scope due to limited need and availability

SPNDs to be thermally tested in MAGNET



Commercial fission chambers to be evaluated in NRAD heated experiment

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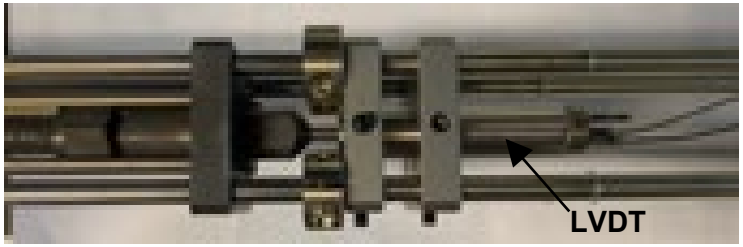
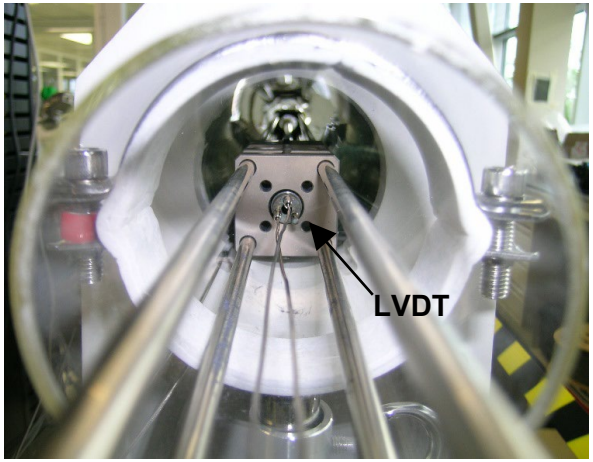
Dimensional Measurement Sensors – Linear variable differential transformers

- Linear Variable Differential Transformers (LVDTs) used to very accurately determine dimensional changes
  - Halden radiation hardened LVDTs are being calibrated in a heated evaluation as part of NEET ASI LVDT activities, but do not have a targeted deployment in MAGNET for FY21 due to limited need and availability for expected tests



LVDT calibration holder developed as part of NEET ASI LVDT activities



LVDT furnace testing as part of NEET ASI LVDT activities

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Evaluation Plan Conclusion –

- Focus of near-term instrumentation and sensor evaluations will include:
  - Distributed sensors for temperature measurements
  - Embedded sensors for temperature and strain measurements
  - Non-contact sensors for temperature, strain, and deformation measurements
- Instrument and sensor evaluations will support test plan objectives outlined in LA-UR-20-20824 during startup, shutdown, steady-state, and during any planned failures
  - Temperature distribution of heat pipe, gap, core block and additional components of SPHERE and MAGNET
  - Stain and deformation of SPHERE and MAGNET test articles
- Additional sensor evaluations including SPNDs and LVDT will be continued under NEET ASI real-time instrumentation activities and deployed in MAGNET as need and availability improve

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