U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

ASI Advanced Sensors and Instrumentation

Optical Fibers

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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Idaho National Laboratory

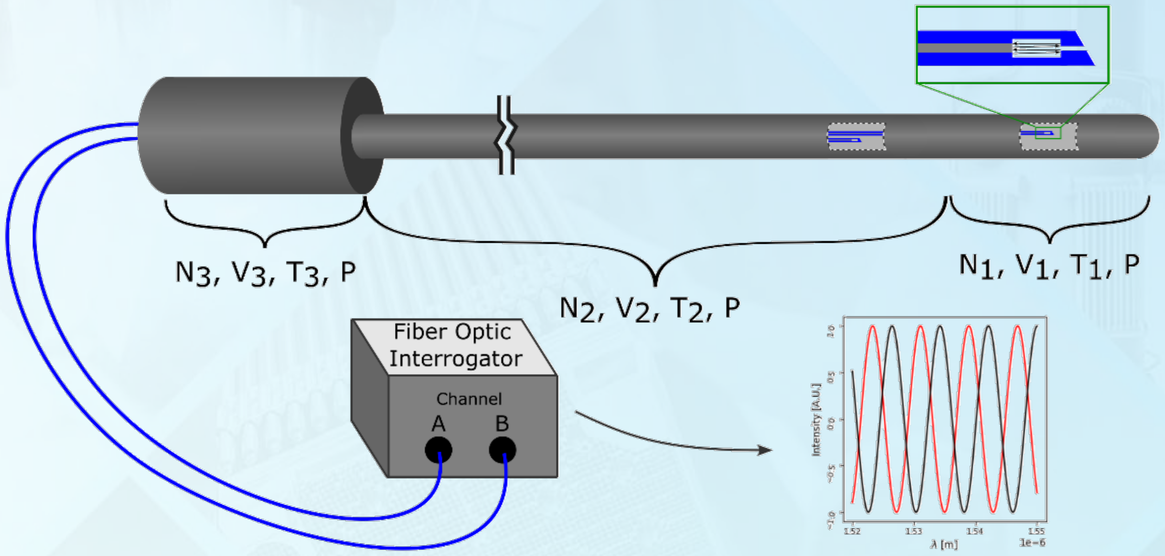
Project Overview

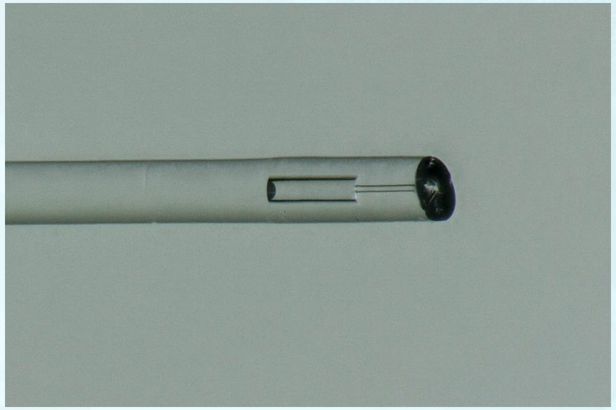
Activities

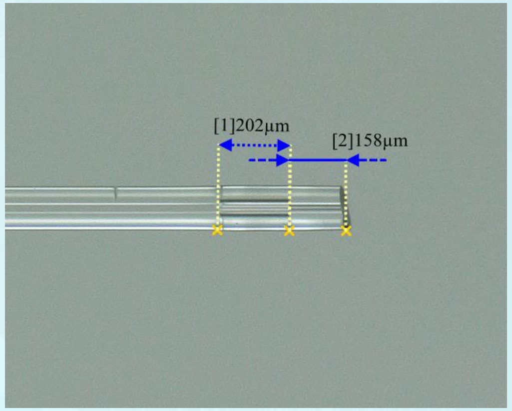
- Radiation Resistance Fiber Optic Temperature Sensor
- In-pile Imaging in the Big Buster Platform
- In-pile test of imaging system in NCSU Reactor
- In-pile Benchmark test of fiber Optic Pressure Sensor

Radiation Resistance Temperature Sensor

- Sensor consists of an open Fabry-Perot cavity allowing gas to flow in and out of cavity
- Sensor is sealed into a capillary with reference volume at constant temperature (noted by V_3)
- Functioning methodology
  - As the location of cavity is heated (Volume 1), the gas density decreases locally, in accordance with ideal gas law
  - Index of refraction changes with gas density in the cavity
  - The interference spectrum from cavity changes with index of refraction







Radiation Resistance Temperature Sensor (Theory Overview)

- Index of refraction of gas located at cavity

$$n = \sqrt{\frac{4\pi N_A \alpha}{\left(\frac{V_1}{T_1} + \frac{V_2}{T_2} + \frac{V_3}{T_3}\right)} \frac{P_i V_T}{R T_1 T_i} + 1}$$

- Fabry-Perot Interference spectrum

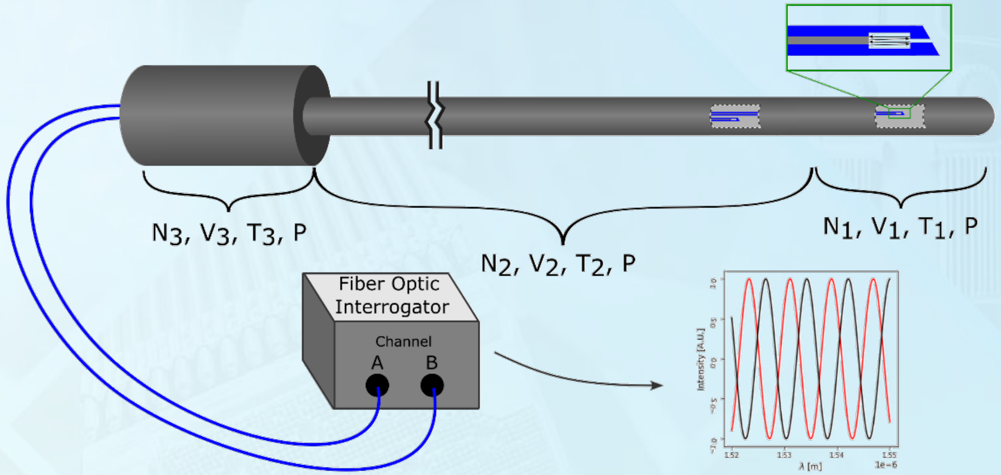
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\left(\frac{4\pi n L}{\lambda}\right)$$

- Peak wavelength in interference spectrum

$$\lambda_p = \frac{2L_0}{m}\left(1 + \alpha_{ex}(\mathrm{T}_1 - T_i)\right) \sqrt{\frac{4\pi N_A \alpha}{\left(\frac{V_1}{T_1} + \frac{V_2}{T_2} + \frac{V_3}{T_3}\right)} \frac{P_i V_T}{R T_1 T_i} + 1}$$

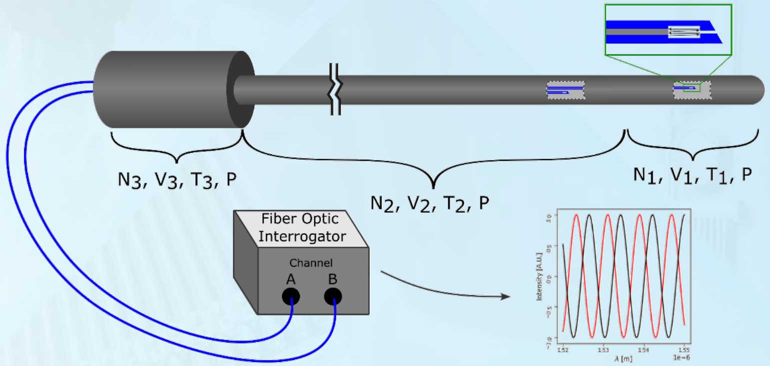
- If ignoring thermal expansion and solving for T_1

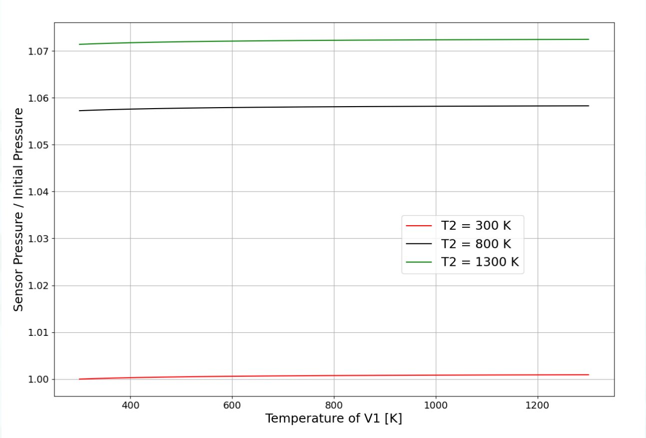
$$T_1 = \left[\frac{4\pi N_A \alpha P_i (V_1 + V_2 + V_3)}{R T_i \left(\left(\frac{\lambda_p m}{2L_0}\right)^2 - 1\right)} - V_1\right] \frac{1}{\left(\frac{V_2}{T_2} + \frac{V_3}{T_3}\right)}$$

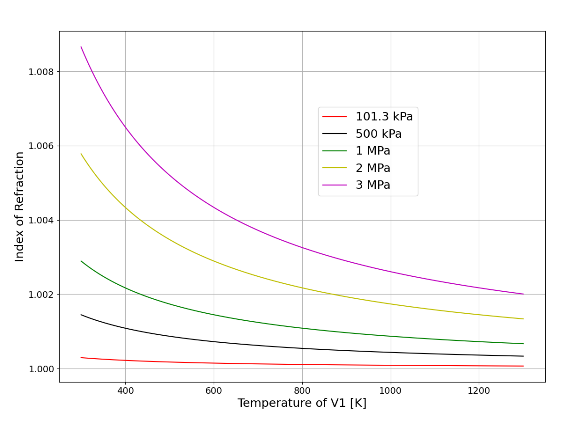


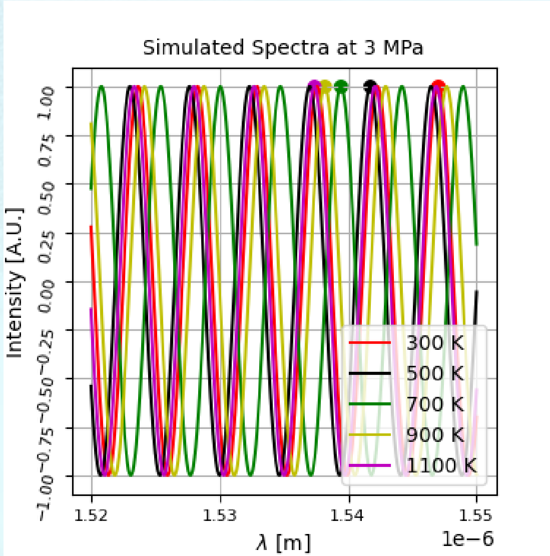
Radiation Resistance Temperature Sensor Modelling Results

- Modelling the sensor packaged in a stainless steel capillary tubing with 1.5 mm (0.062”) OD. A reference volume of 1.5 cm X 4 cm. (0.6” X1.6”)
  - Very little pressurization due to temperature change in the capillary region due to “large” reference volume
  - Even relatively insensitive to all of volume 2 increasing temperature
- Sensitivity is largely “tuned” by changing the gas composition or initial pressurization
  - Higher pressure is required for maintaining sensitivity at elevated temperatures
- Simulated spectrum demonstrates sensitivity and peak tracking challenges



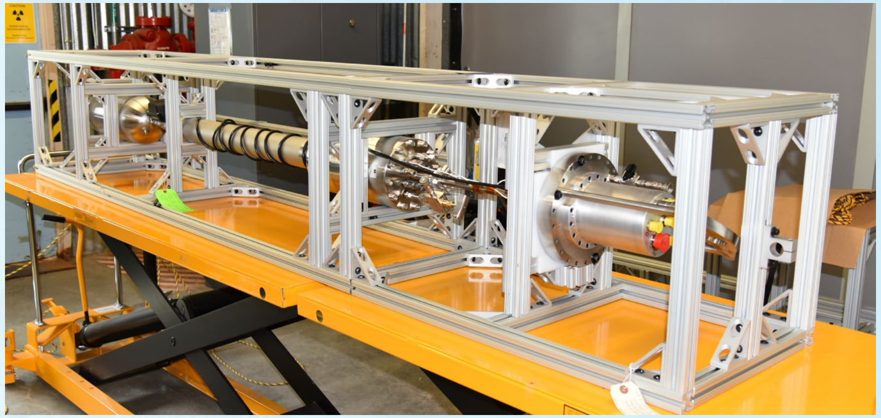




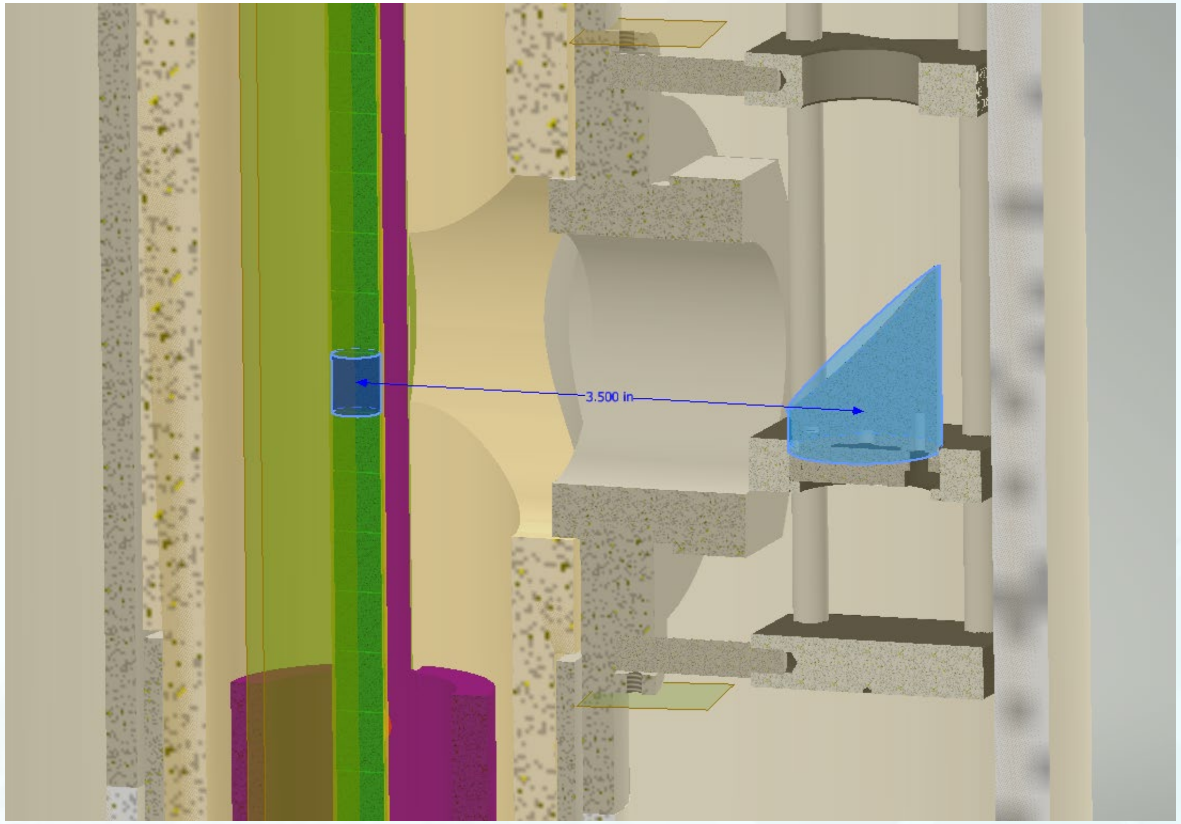


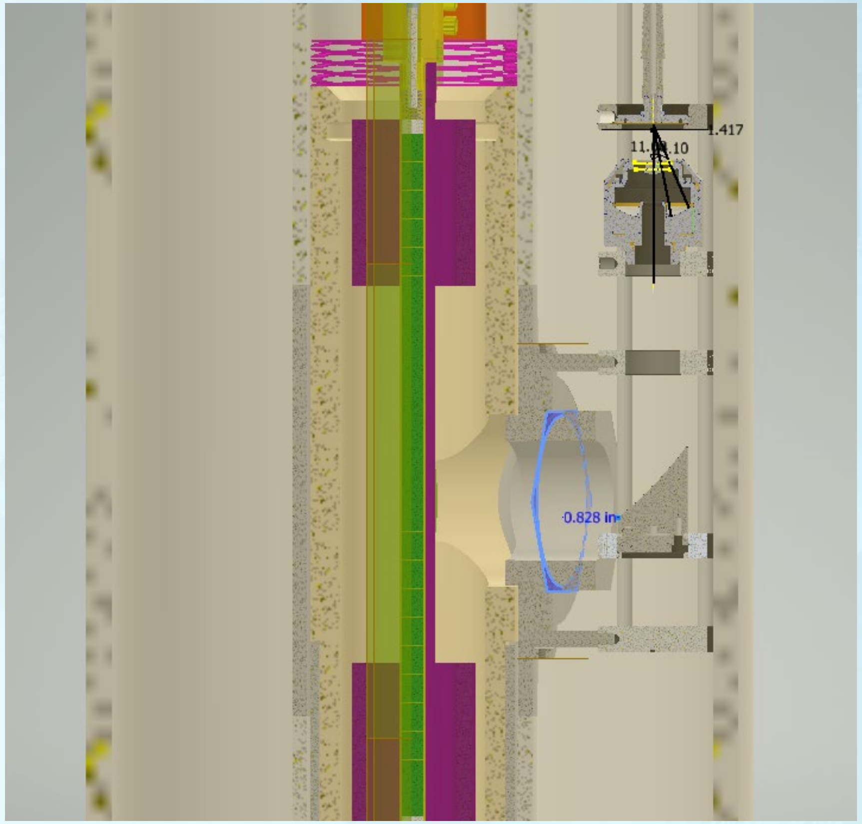
In-pile Imaging in Big Buster

- The Transient Reactor Test Facility (TREAT), conducted irradiation experiments that are most likely to benefit from in-pile imaging.
  - Large irradiation position
  - Destructive Testing
  - Low Neutron Fluence (although high flux) testing
- Big Buster – The primary vessel used for irradiation experiments in the TREAT reactor
  - Establishing a demonstration capability
- Challenges have been identified from previous laboratory and irradiation testing
  - Radiation Induced Emission
    - Cherenkov and radioluminescence
    - Need to illuminate within a spectral range
  - Radiation Induced Attenuation
    - Need to utilize near infrared
  - Radiation induced Index of Refraction Change
    - Focal length of lenses changing
    - Reflective optics



In-pile Imaging in Big Buster





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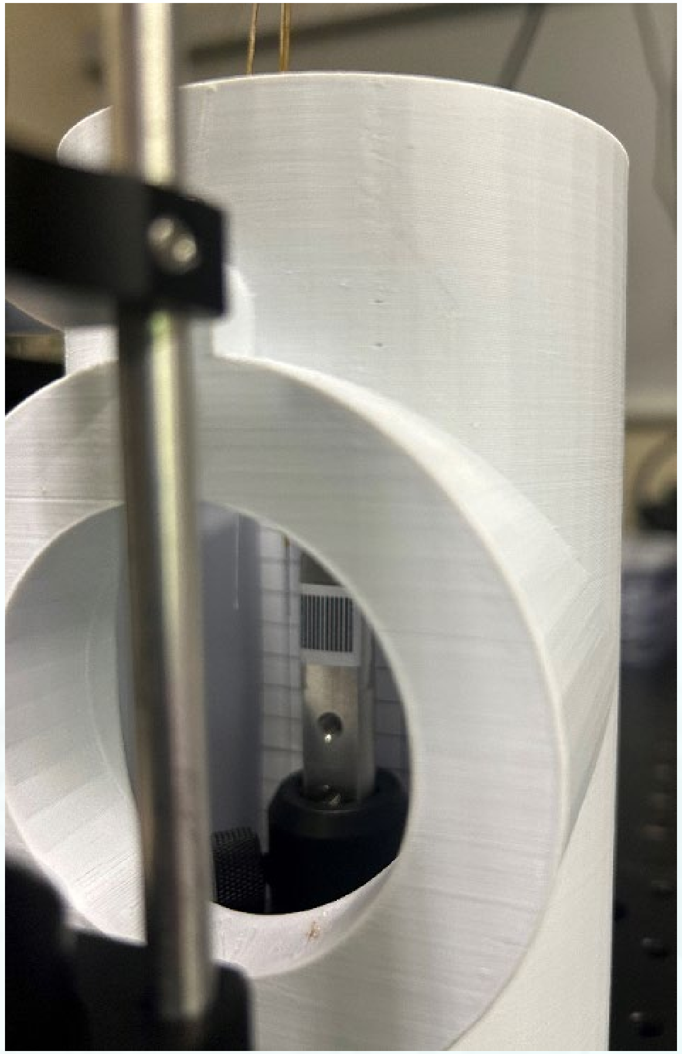
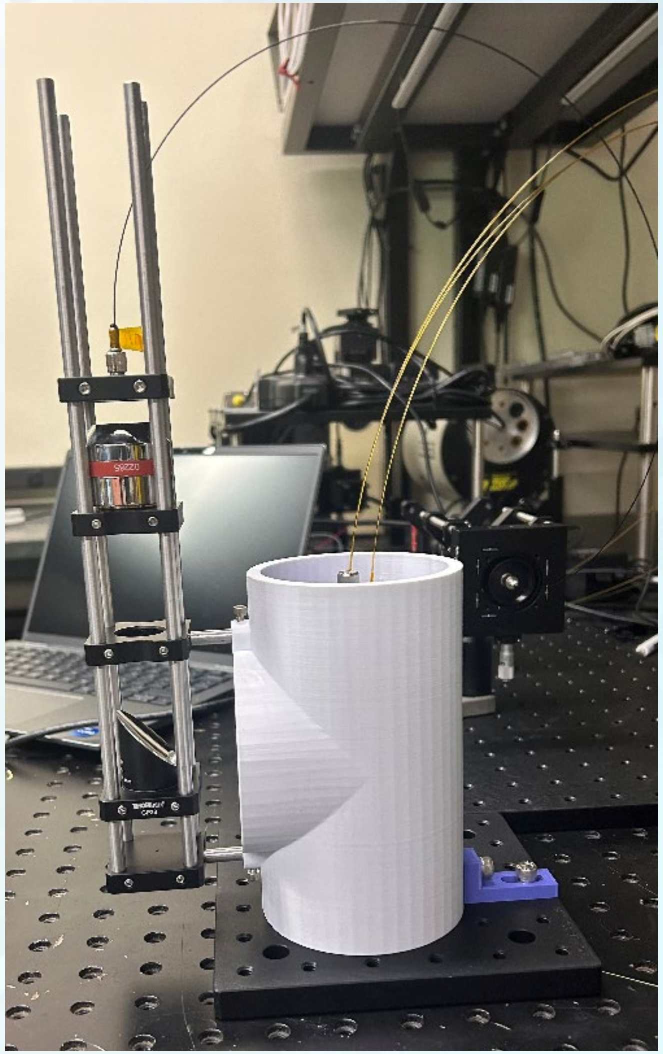
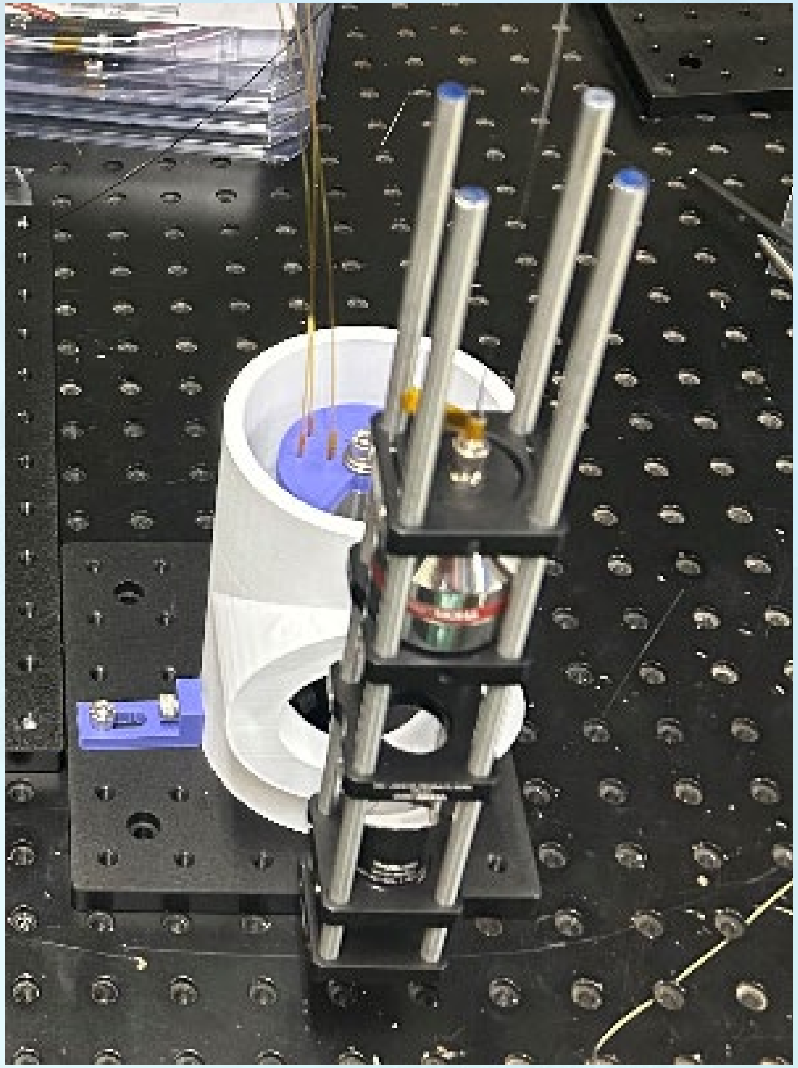
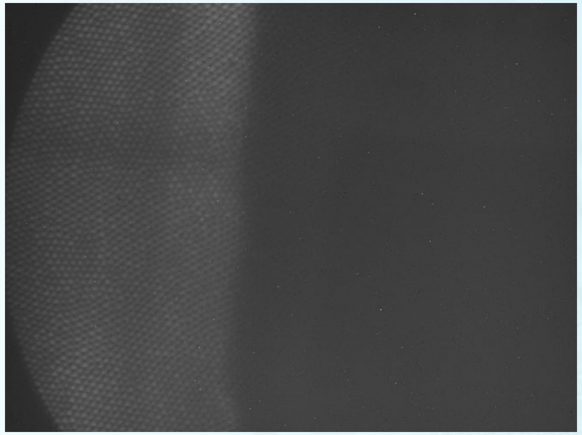


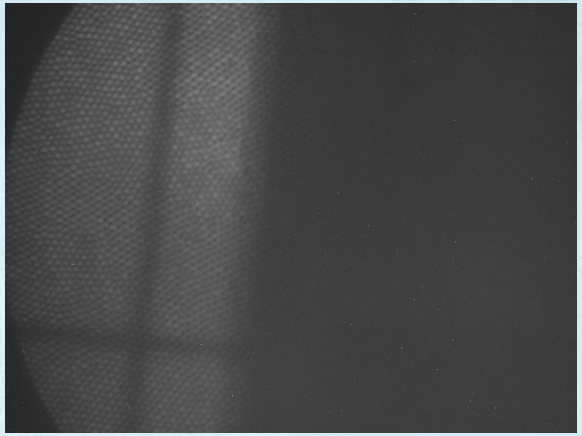




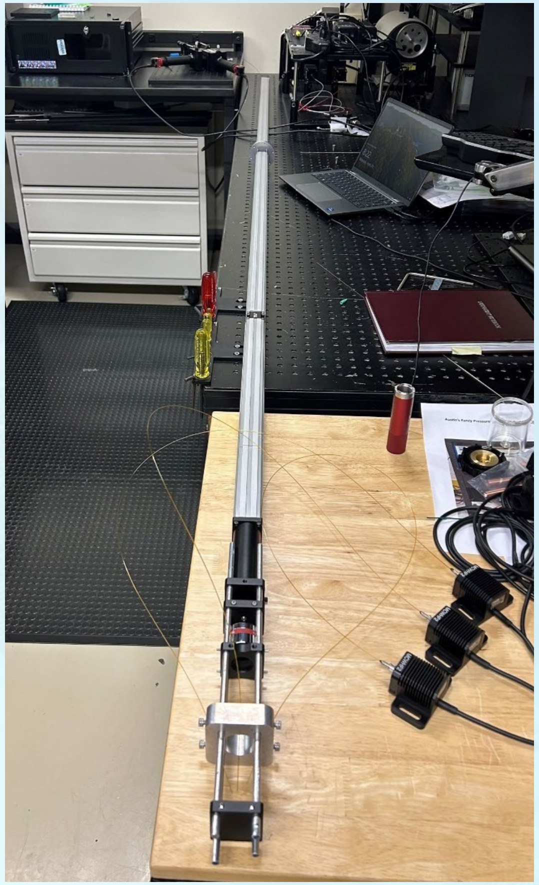
In-pile Imaging in Big Buster

- LOCA testing of fuel pins is a likely candidate for in-pile imaging
  - Ballooning Behavior
  - Rupture, Fuel Fragmentation Relocation and Dispersal
- Image was collected from the edge of "rod" with a grid in the background
- Some different iterations were tried with focusing point, and field of view.
  - Depending on the specific objective of an experiment this can be optimized
  - Flat mirror vs off-axis parabolic
  - Distance from reflective objective.

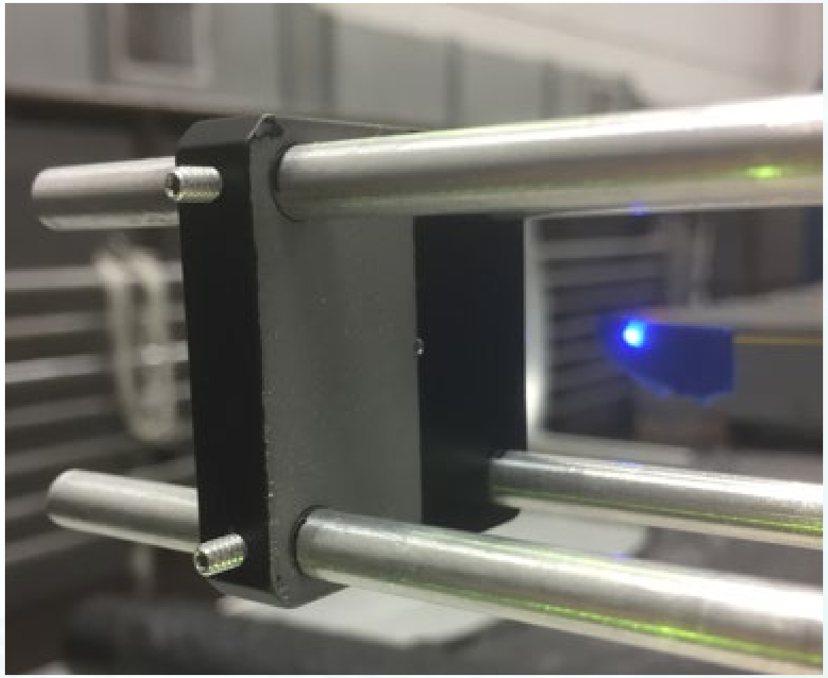


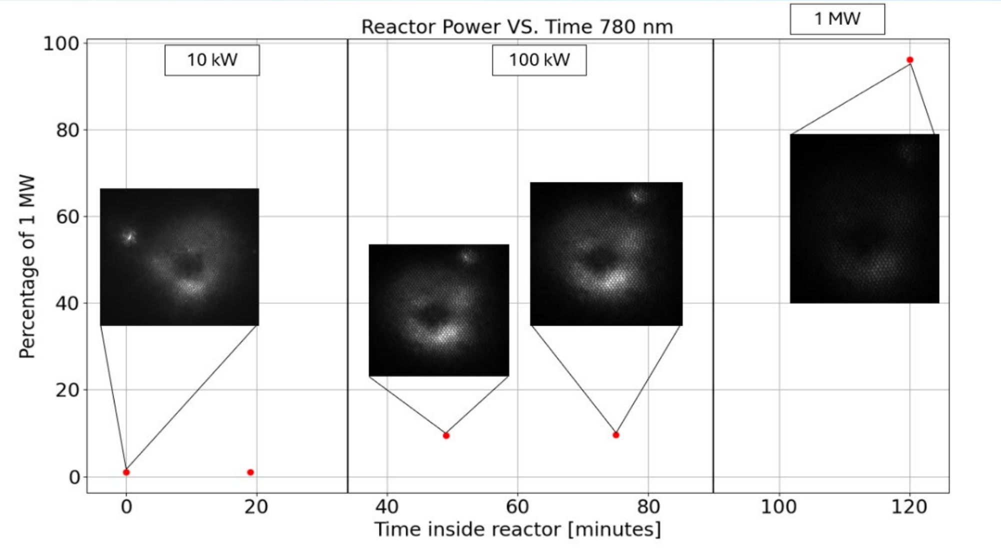


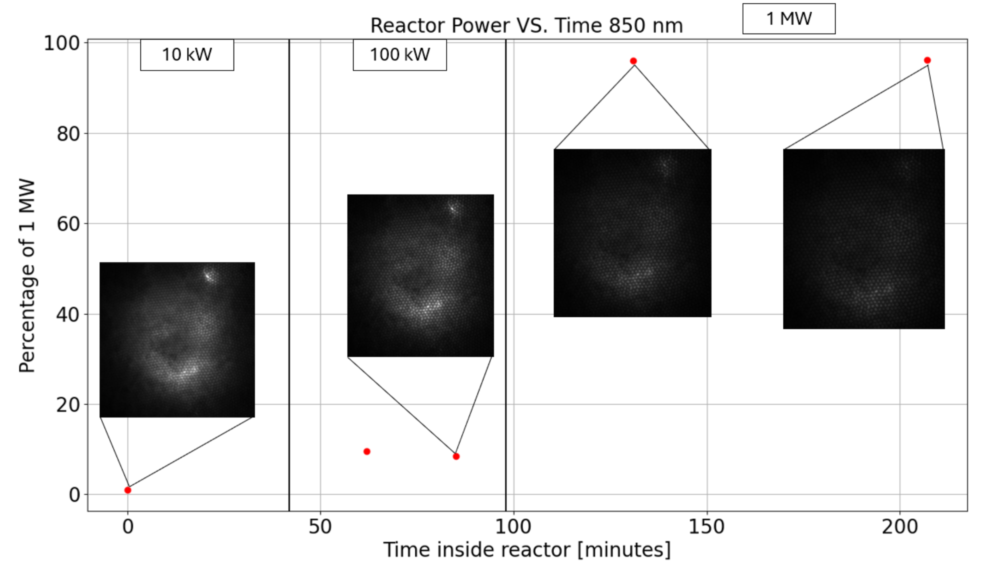
In-pile Imaging in NCSU Reactor



In-pile Imaging in NCSU Reactor







Pressure sensor

- The INL Developed pressure sensor was incorporated into an AFC experiment, but was unfortunately damaged during the fueling of the experiment. As a result the milestone has been delayed.
- The sensor is incorporated into the next experiment in the series which is *currently* planned to be irradiated end of January.

Concluding Remarks

- In-pile imaging has been significantly matured, some challenges still remain but we believe technical feasibility has been demonstrated. Optimization and improvements have been identified but are currently not funded.
- Radiation Resistant Temperature Sensor – INL applied for preliminary patent. Currently not funded through ASI, but may submit a TCF proposal. More testing is warranted and needs to be completed to fully evaluate the sensor potential (and limitations).

FY2025 Future work

- Pressure sensor design revision
  - Reduce drift, improve manufacturability, ruggedized design
- High Speed, High temperature, Radiation Resistant Fiber Optic Pyrometry
  - Build on ~6 year of experience deploying fiber optic pyrometry in irradiation experiments
    - Previously used system is spectrometer-based data collection with custom multi-spectral data reduction to minimize radiation effects.
    - Main current limitations the current system are slow speed at low temperatures (requires long exposure time)
    - New system will utilize photodiode-based system but attempt to maintain as much spectral information as possible to maintain a similar data reduction algorithm to what is currently used.

Thank You

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