DOE – Phase I STTR program

Optical Fiber Based Distributed Radiation Detection

Derek Rountree – Luna Innovations

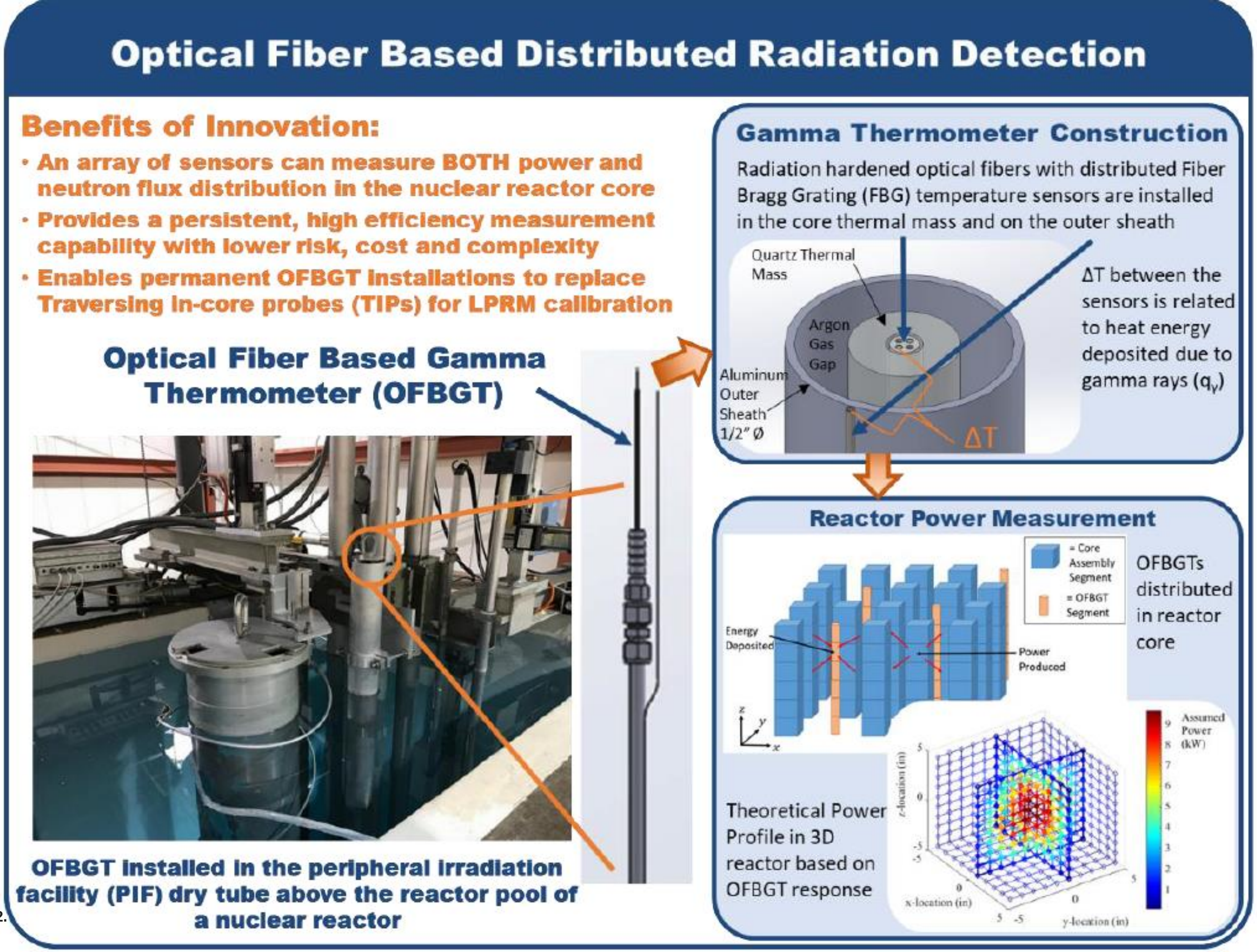
November 6th, 2024

Program Concept Overview

University Partner:

Dr. Thomas E. Blue at The Ohio State University

THE OHIO STATE UNIVERSITY



Birri, Anthony, and Thomas E. Blue. "Methodology for inferring reactor core power distribution from an optical fiber based gamma thermometer array." *Progress in Nuclear Energy* 130 (2020): 103552.

Program Objectives

OVERALL GOAL

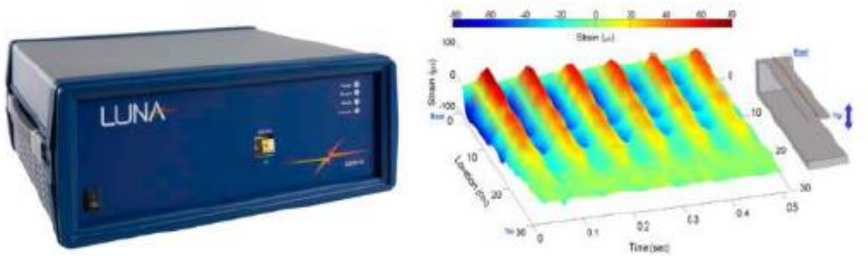
Transition earlier work by others on Optical Fiber Based Gamma Thermometers (OFBGT's) into a commercial product.

PHASE I OBJECTIVES – 9 month program from July 2023 – April 2024

- Develop early commercial prototype sensors with increased TRL
- Test sensors in the OSU reactor to demonstrate power measurement
- Expand sensor capability to include both gamma and neutron flux measurements
- Characterize accuracy and repeatability of sensors
- Determine longevity over temperature and radiation exposure/fluence

Luna Enabling the future with fiber

- Luna is a global leader in fiber optic sensors and instrumentation with a focus on distributed sensing.
- Luna instruments have been used in the prior research and development efforts for OFBGT's and many other sensors.
- As a public company with extensive production and engineering capabilities, Luna is uniquely qualified to transition new sensor technologies into commercial applications.

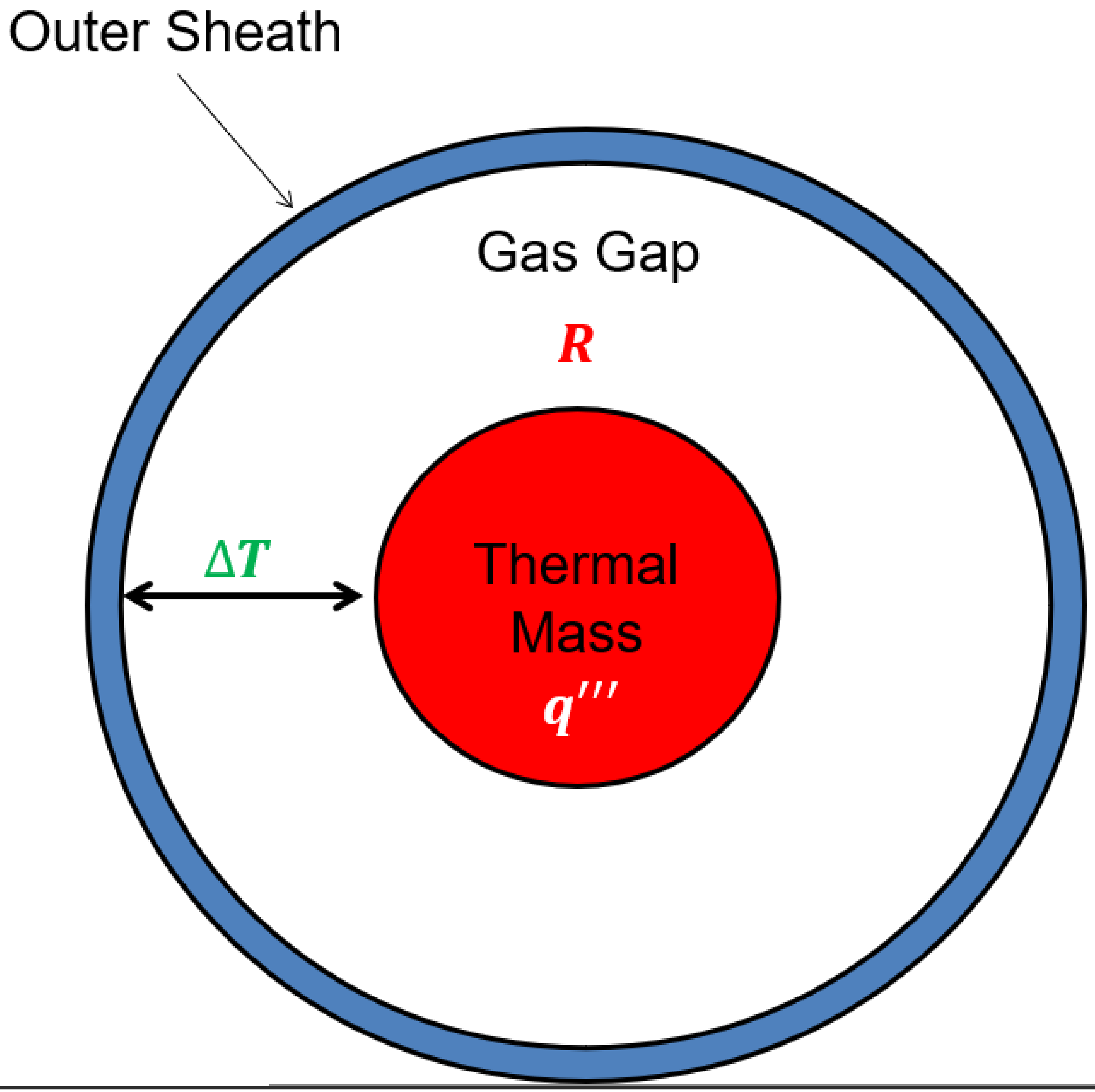


The ODISI-B recording the time response of the strain of a cantilever beam oscillating at its natural frequency.

The ODISI 6100 instrument (top), temperature data on a car radiator shown with point cloud visualization.

What is a Gamma Thermometer?

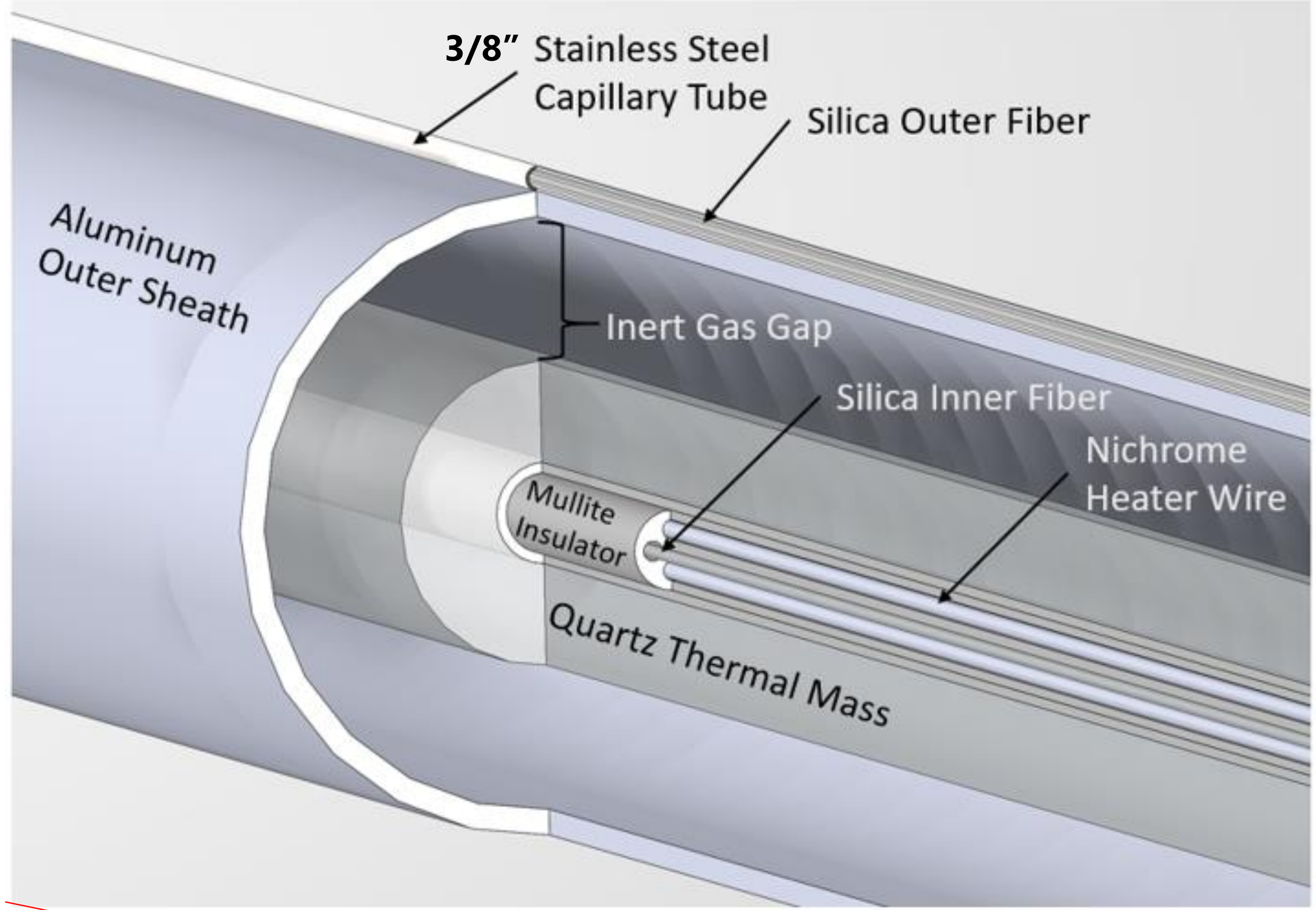
- A gamma thermometer consists of:
  - Thermal mass, in which heat energy is deposited due to gamma rays (q''')
  - Outer sheath, which contains the thermal mass
  - Gas gap, which is responsible for a thermal resistance (R) between the thermal mass and outer sheath, thus resulting in a ΔT
- If one measures ΔT, and the relationship between q''' and ΔT is known, then one can determine q''' ($q''' = \Delta T / R$)

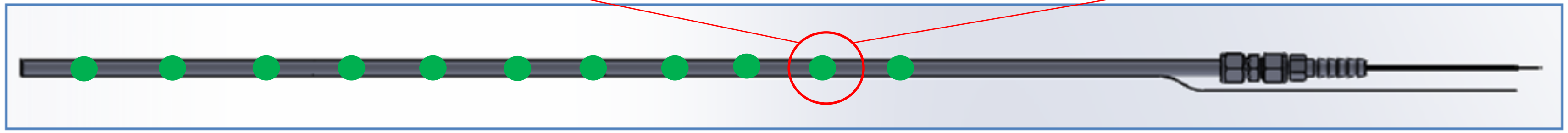


Sensor Design

- Active sensor region consists of a thermal mass, inert gas gap, and an aluminum outer sheath

- Fibers are inscribed with customized FBGs to create a strong OFDR signature that is robust to radiation exposure



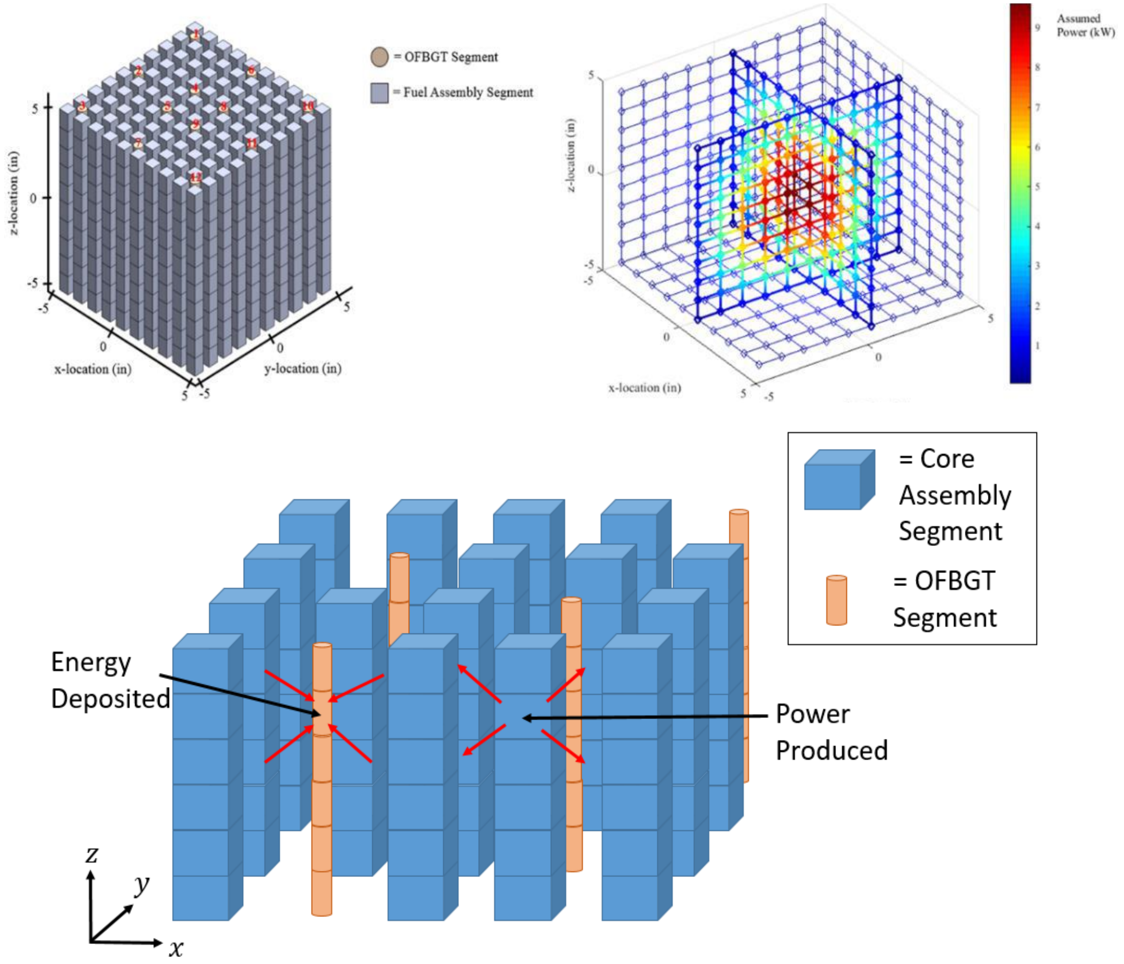


Preliminary Target Performance Criteria

Specification	Phase I Goal	Overall Project Goal
Temperature Range	0 - 300°C	0 - 800°C
Number of FBG temperature sensors in an OFBGT	10	20+
Measurement Rate	1 Hz	10 Hz
Temperature Resolution	1.0°C	0.1°C
Temperature Accuracy	2% F.S.	1% F.S.
Reactor Power Accuracy	5%	1%
Neutron Flux Accuracy	Best effort	5%
OFBGT length	3 ft.	10 ft.

Benefits of the technology

- OFBGTs could simply be used to calibrate LPRMs
  - Because an OFBGT is a distributed sensor, one could perform this calibration with less wiring with an OFBGT than with a chain of thermocouple-based GTs. Improvement over TIP’s.
- However, because of the distributed sensing capability of the OFBGT, it presents the opportunity for power inferencing
  - An array of OFBGTs in a reactor core could provide 100s to 1000s of data points
  - If one considers a segmented core, one could use response function equations between OFBGT segments and reactor core segments to obtain a power distribution of 100s to 1000s of segments
  - Using different materials can create a neutron sensitive probe, which would allow for co-located gamma and neutron measurements to be made.



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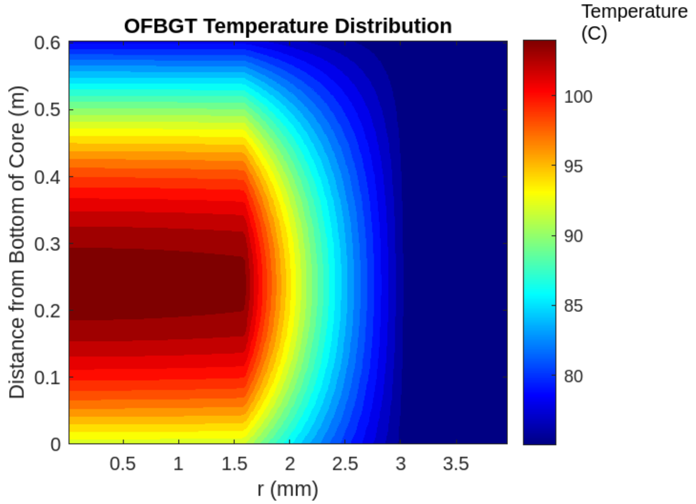
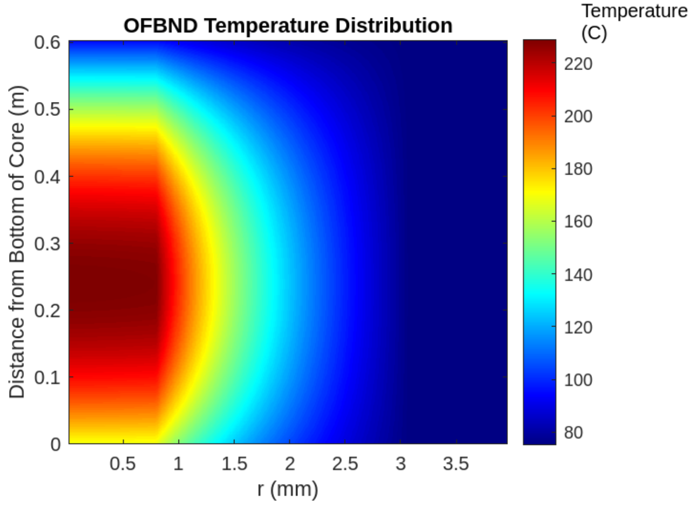
Model and simulate performance of OFBGT sensors for measurement of reactor power and neutron flux (OFBND)

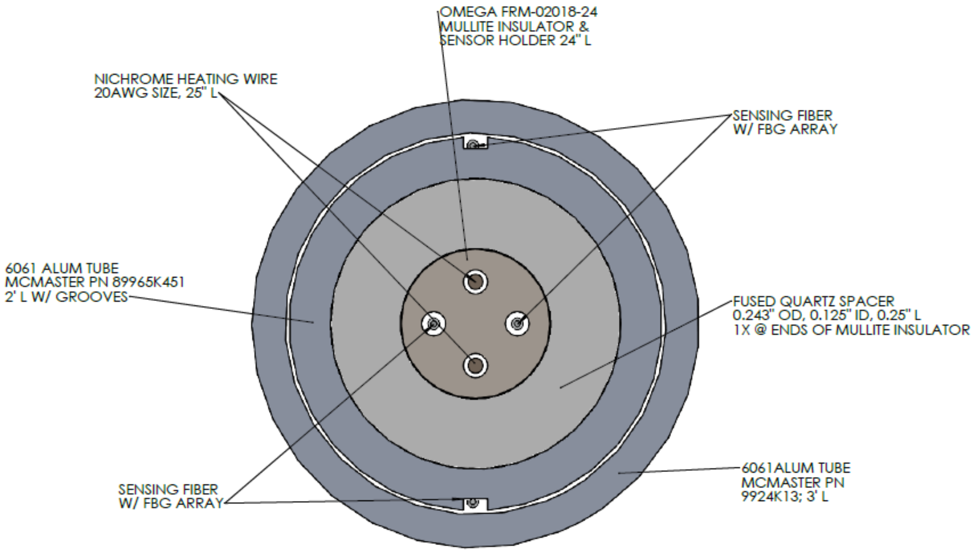
	OFBGT	OFBND
Thermal Mass Material	Mullite	Borosilicate Glass
Thermal Mass Radius (mm)	1.588	0.794
Gas Gap Thickness (mm)	1.5	2.3
κ_{TM} $(\frac{W}{mK})$	5	1.15
q' (W/m)	5.77	16.6
ΔT **from Python (C)**	27.1	159.4
ΔT **from MATLAB (C)**	29.66	154.8

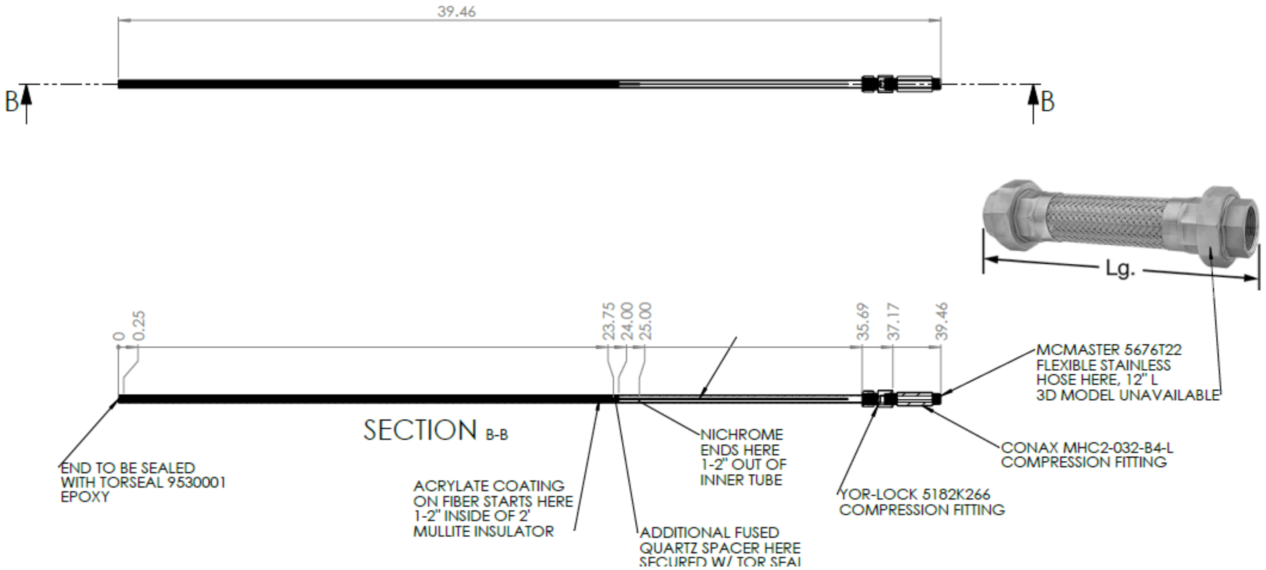


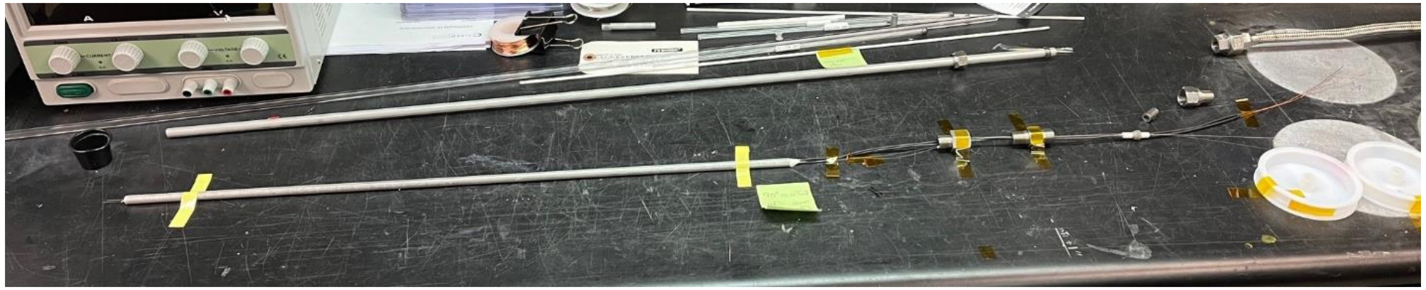


Birri, Anthony, Christian M. Petrie, and Thomas E. Blue. "Analytic thermal model of an optical fiber based gamma thermometer and its application in a university research reactor." *IEEE Sensors Journal* 20, no. 13 (2020): 7060-7068.

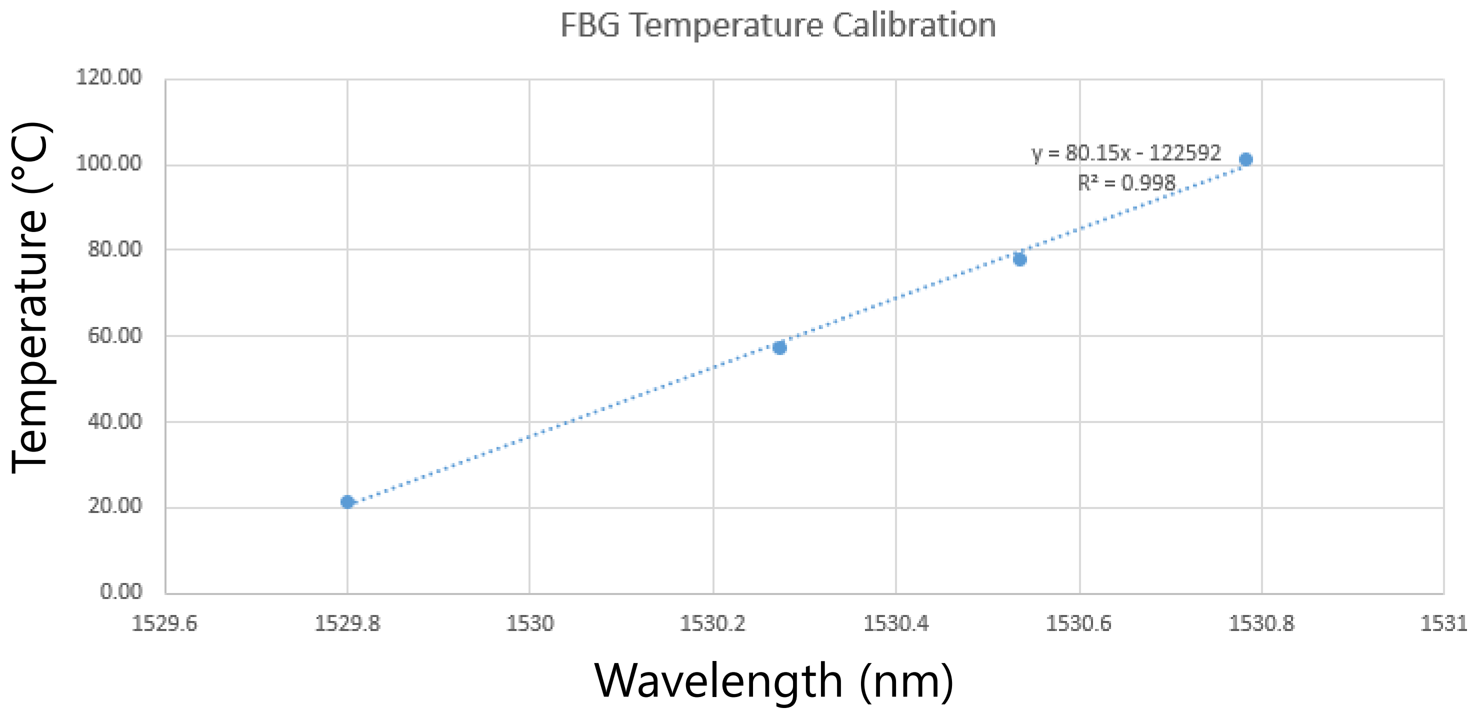
Fabricate OFBGT sensors

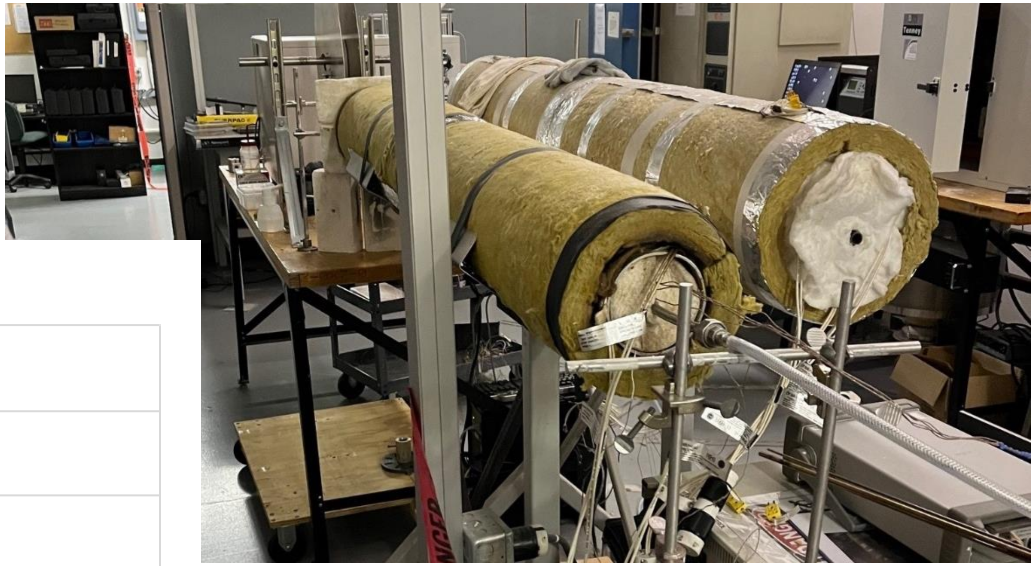




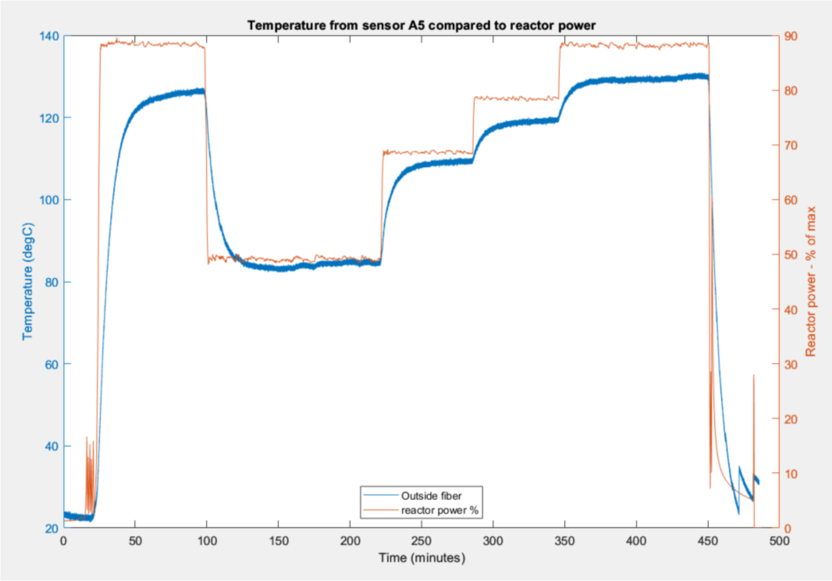


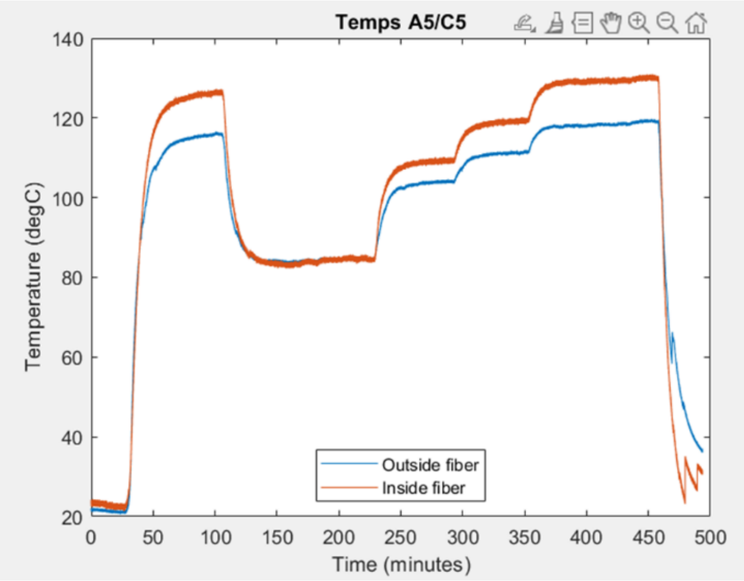
FBG array thermal calibration

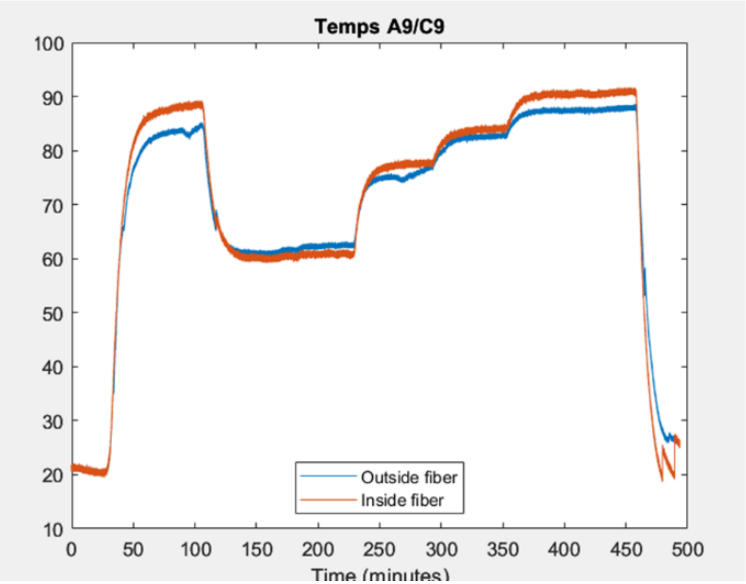




Comparison of OFBGT internal and external temperatures

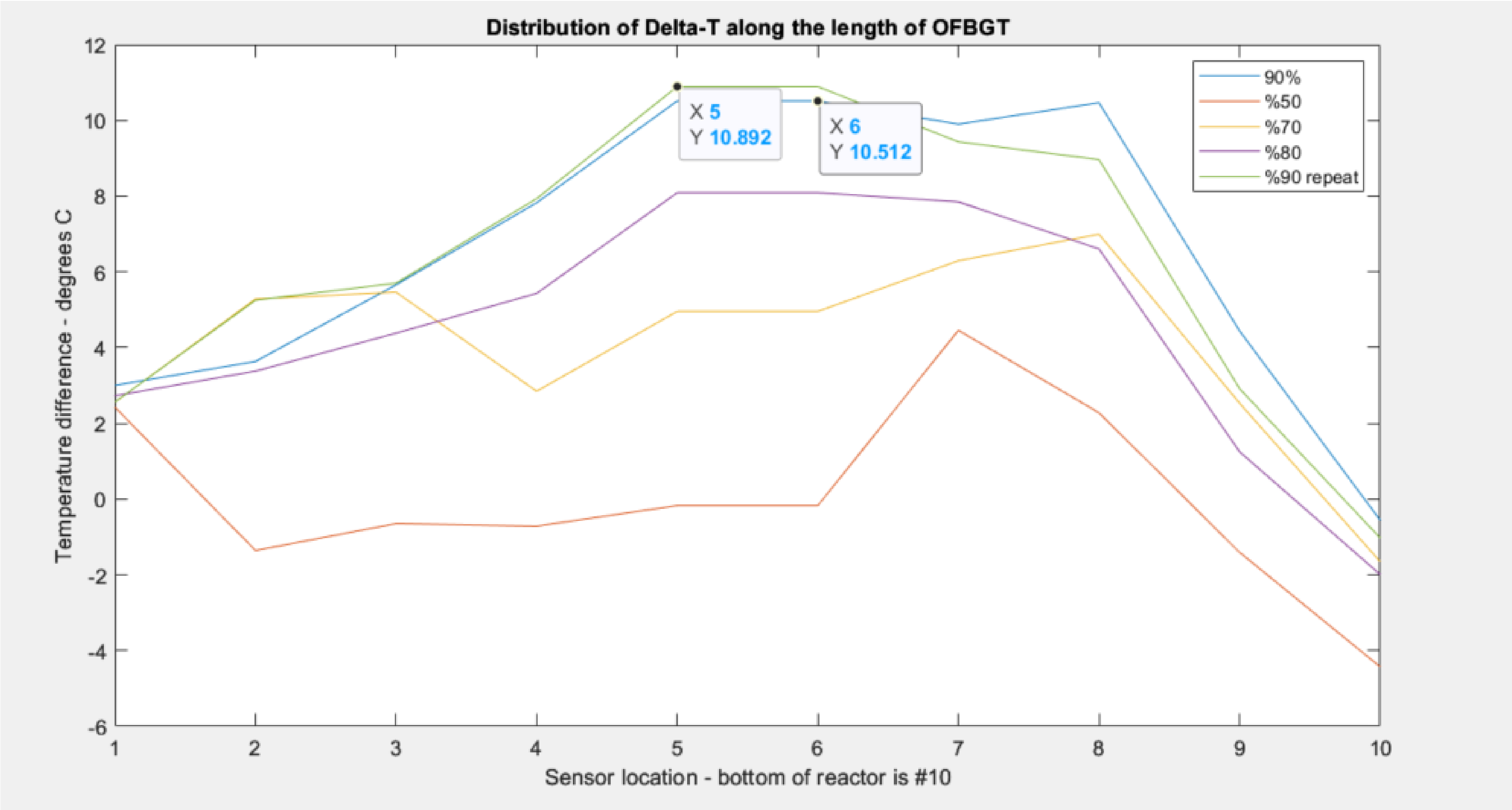






Continuous OFBGT measurement in the OSURR CIF

100% power → 2x1013 n/cm2/s



The Team

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  - S. Derek Rountree
- OSU
  - Tom Blue
  - Wyatt Panaccione
- ORNL
  - Tony Birri

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