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

ASI Advanced Sensors and Instrumentation

Gamma Thermometer Irradiation in the HFIR Spent Fuel Pool

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

October 30 – November 2, 2023

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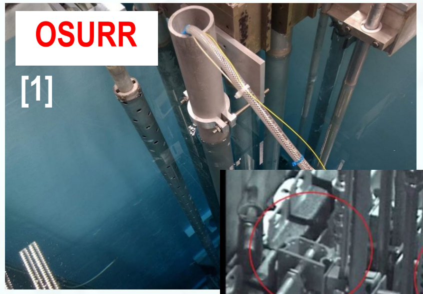
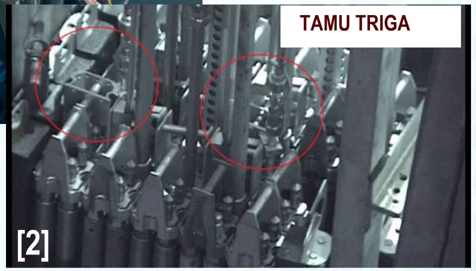
Project Overview

- The goal of this research is to develop, model, and demonstrate an optical fiber-based gamma thermometer (OFBGT) in an intense gamma-ray field
- The irradiations are to occur in the spent fuel pool at HFIR
  - Source of high gamma dose rates
  - Different spent fuel elements can provide different source strengths
- These OFBGT irradiations should provide axial distributions of gamma dose rates in spent fuel pools, and we can compare with HFIR predictions
- This work aligns with the optical gamma thermometer irradiations work conducted by OSU and TAMU and power inferencing method development occurring at ORNL

Various Gamma Thermometer Experiments

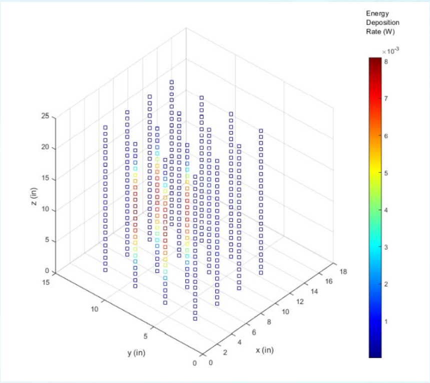




This Work

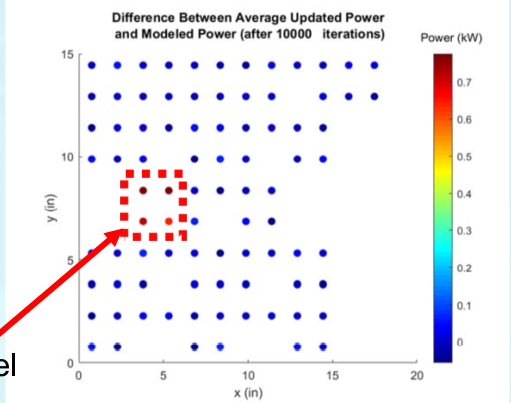
Power Inferencing (WP: CT-23OR070206)

Perturbed Sensor Response



Data Analytic Methods

Perturbation Inferencing

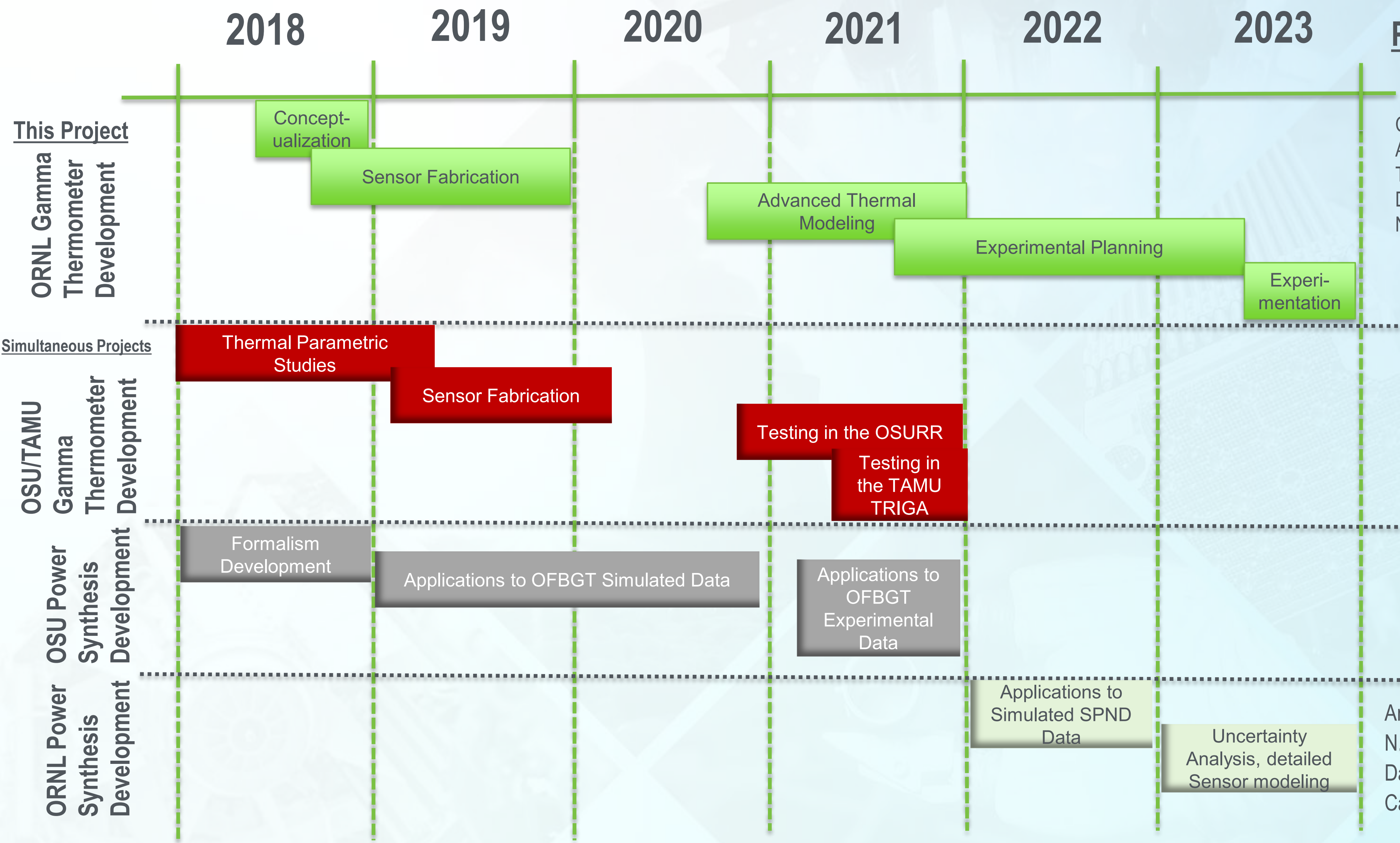


Perturbed Fuel Pins

[1] DOI: osu1626189906070566

[2] Thesis, Gates T. (2022)

Timeline of this project and other relevant projects



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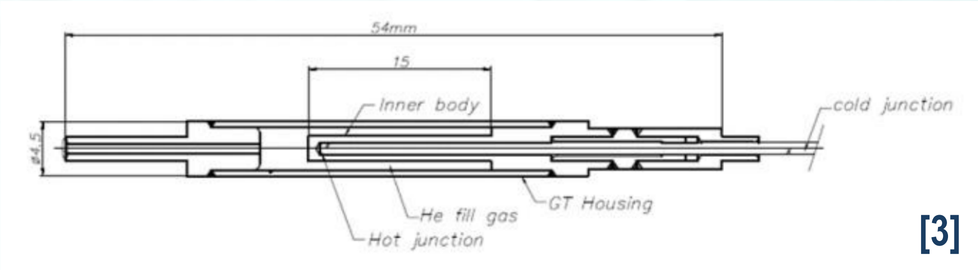
Funding Sources

NSUF Nuclear Science User Facilities
ASI Advanced Sensors and Instrumentation
NEUP Nuclear Energy University Program U.S. Department of Energy
NEUP Nuclear Energy University Program U.S. Department of Energy
NNSA National Nuclear Security Administration
ASI Advanced Sensors and Instrumentation

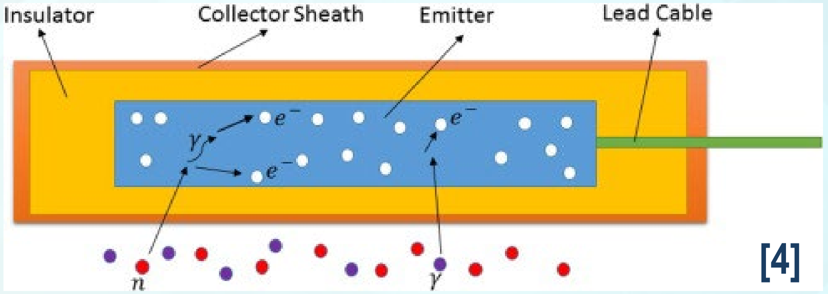
Technology Impact

- An OFBGT can provide a distribution of gamma dose rates along its axial length. The method can be described as calorimetry
  - Based on a distributed (~mm resolution) measurement of temperature differences between silica fibers that correspond to heating rates
- An OFBGT is part of a suite of sensors that are intended for neutron/gamma detection in situ or ex situ
  - These sensors include standard GTs, SPNDs, SPGDs, ion chambers
  - These types of sensors are used by industry to reconstruct the power distribution and monitor things like power peaking, power tilts, oscillations, etc.
- The OFBGT may offer a unique solution to get higher fidelity power distribution information in real time
  - A single OFBGT can provide 100s to 1000s of data points along its axial length
  - Also, a single OFBGT could replace a string of SPNDs/GTs in a reactor core

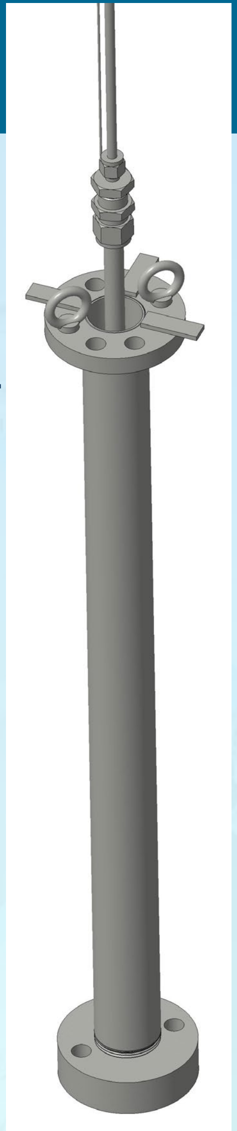
Standard gamma thermometer



SPND



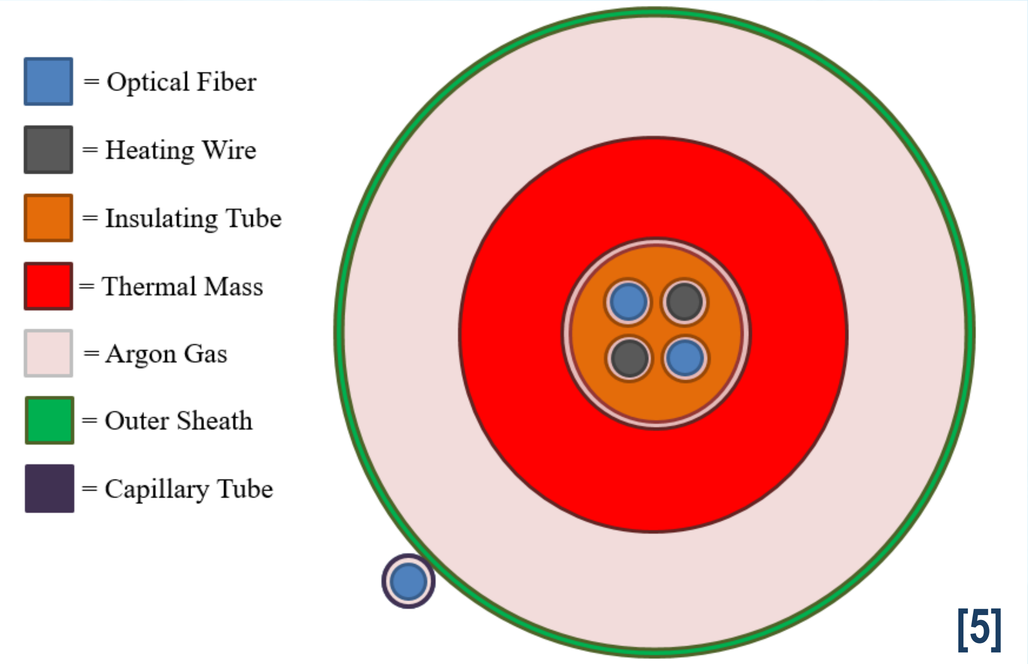
ORNL Gamma Thermometer Experiment



[3] DOI: 10.1051/epjconf/202022504003
[4] DOI: 10.1016/j.anucene.2017.09.048

What is a gamma thermometer?

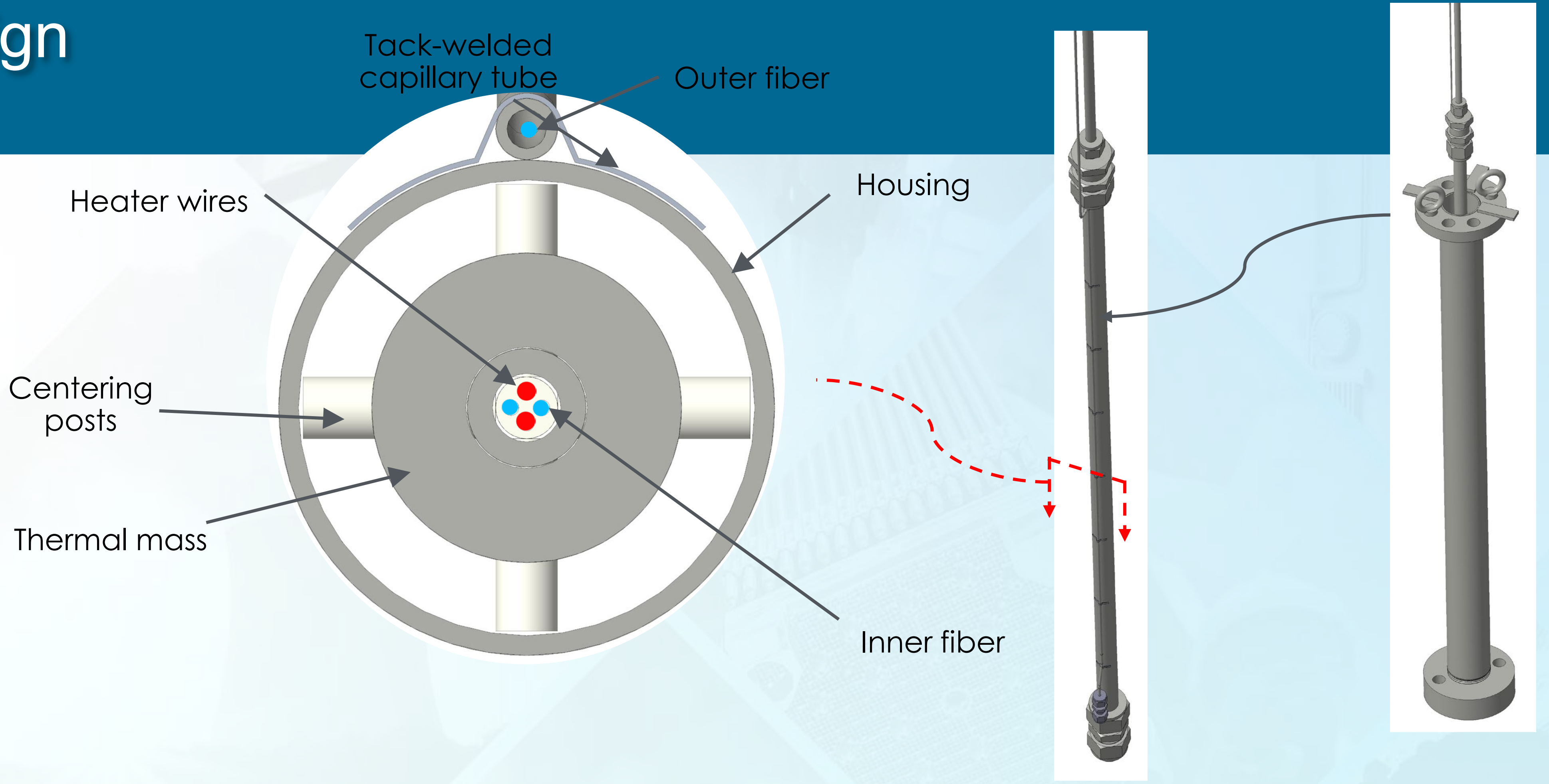
- A gamma thermometer consists of:
  - Thermal mass, in which heat energy is deposited due to gamma rays ($\boldsymbol{q'''}$)
  - Outer sheath, which contains the thermal mass
  - Gas gap, which is responsible for a thermal resistance ($\boldsymbol{R}$) between the thermal mass and outer sheath, thus resulting in a $\Delta\boldsymbol{T}$ ($\Delta\boldsymbol{T}=\boldsymbol{q'''}\boldsymbol{R}$)
- In an optical fiber-based gamma thermometer (OFBGT) specifically, optical fibers monitor the temperature of the thermal mass and the outer sheath using OFDR
- The relationship between $\boldsymbol{q'''}$ and $\Delta\boldsymbol{T}$ is determined by calibration with a nichrome heating wire
- The OFBGT, unlike a thermocouple-based GT, can be used as a distributed sensor

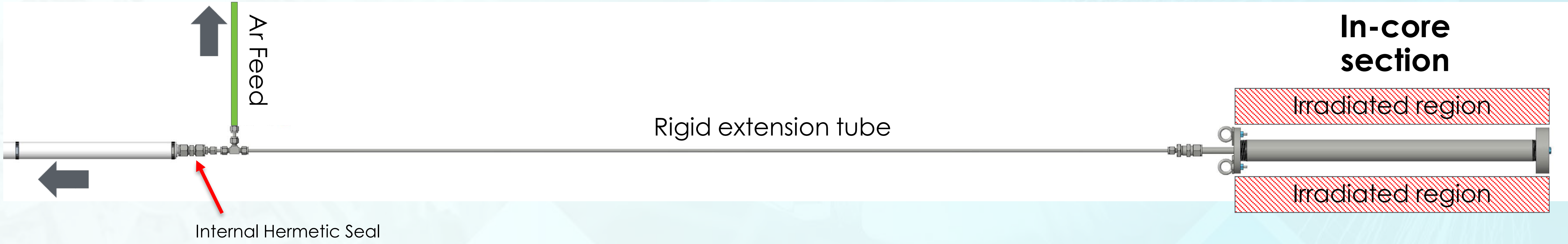


[5] DOI: 10.1109/JSEN.2020.2978424

Experiment Design

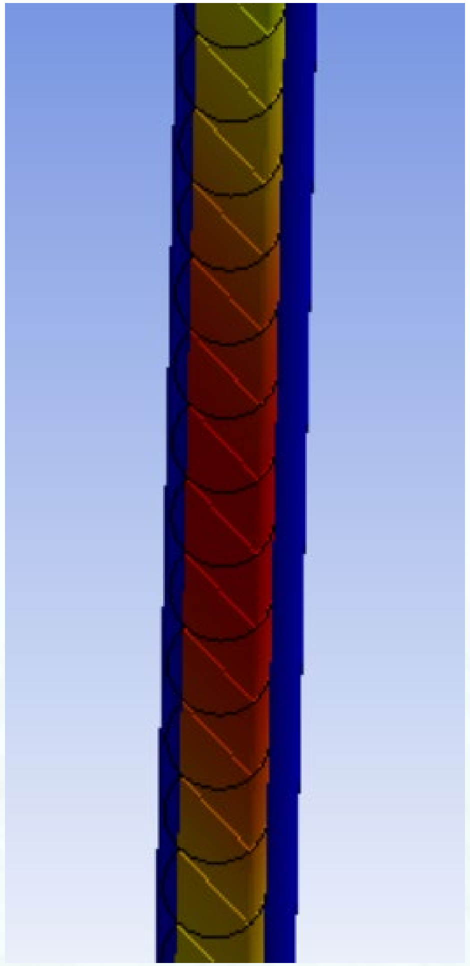
- 2 ft active sensing region with thermal mass
- Thermal mass centered by zirconia spacers
- Gas pressure regulated through feedline
- Capillary fiber tack welded to outer sheath





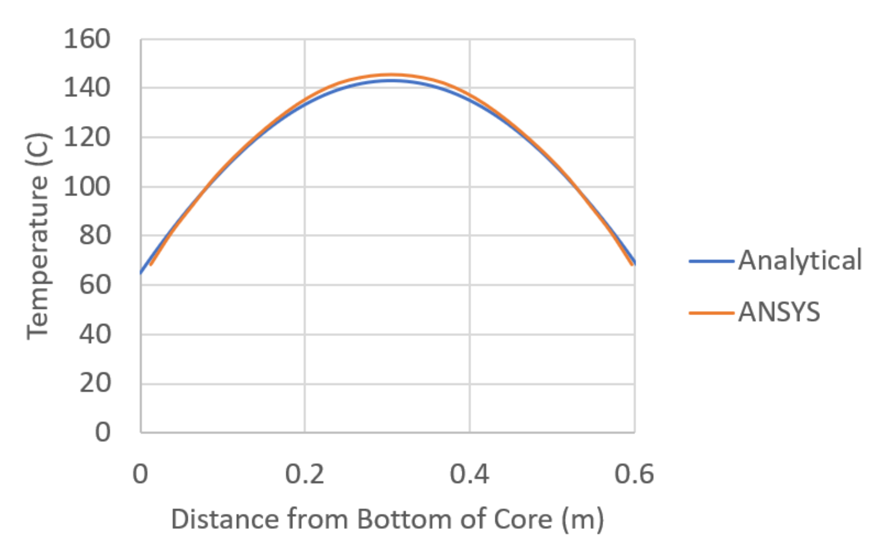
Thermal Modeling Results

ANSYS modeling

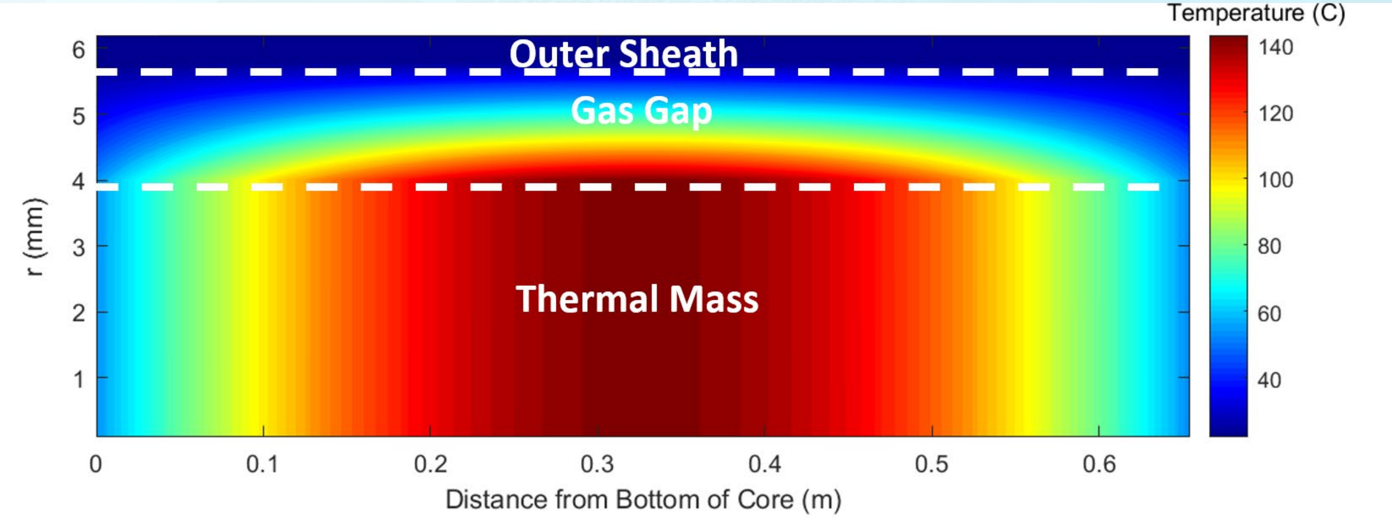


- The ORNL OFBGT has been modeled in ANSYS and analytically to determine the expected temperature profile (10 days from cycle end)
- Temperature depended thermal conductivities considered
- Additional output from this modeling is expected modulation of temperature profile in axial direction

Model verification

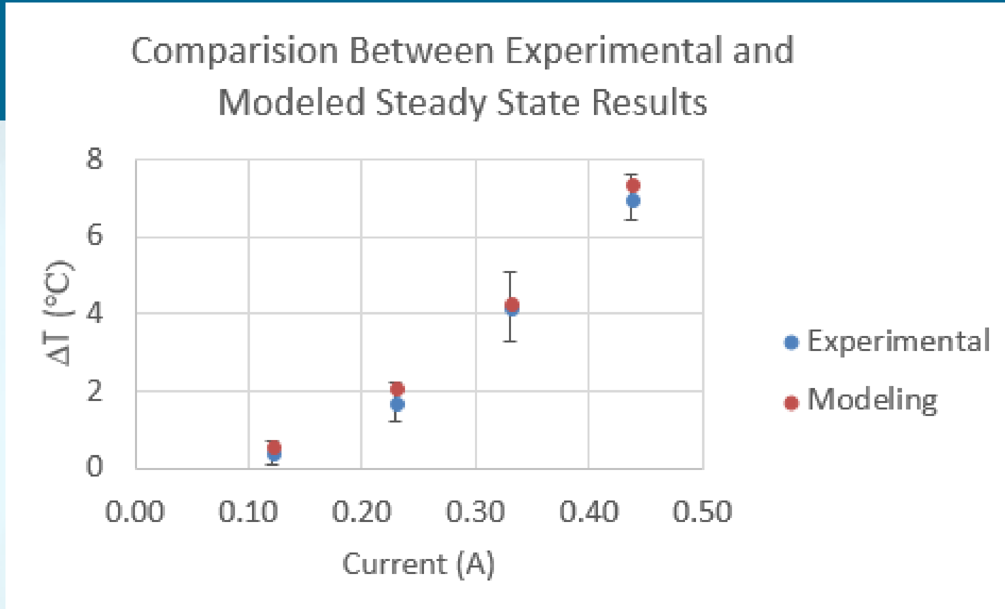


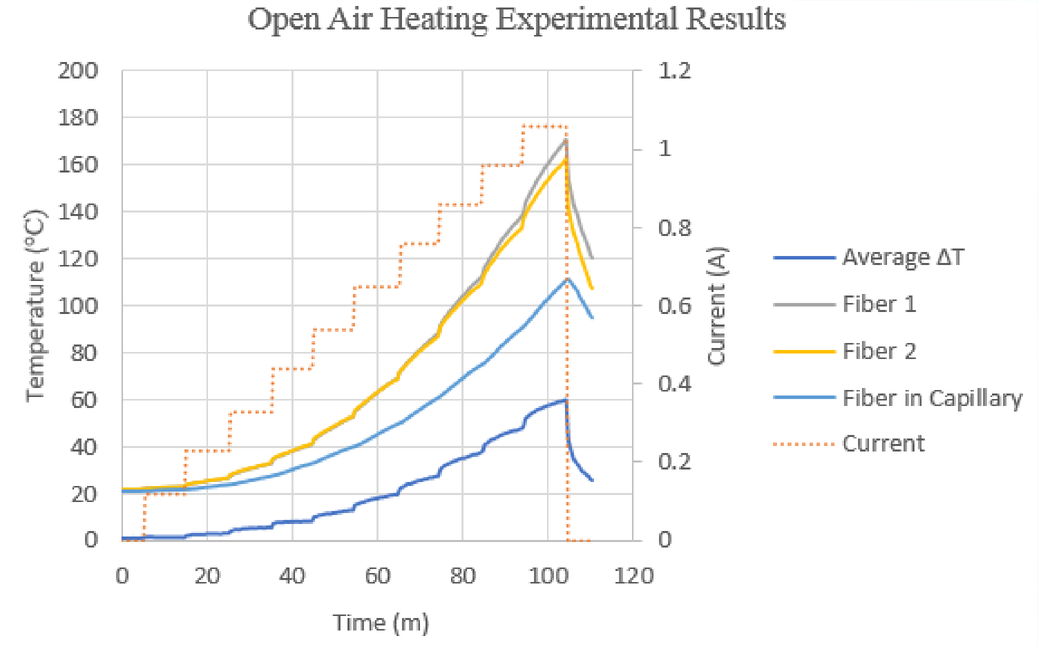
Analytical Model



Preliminary Testing Results

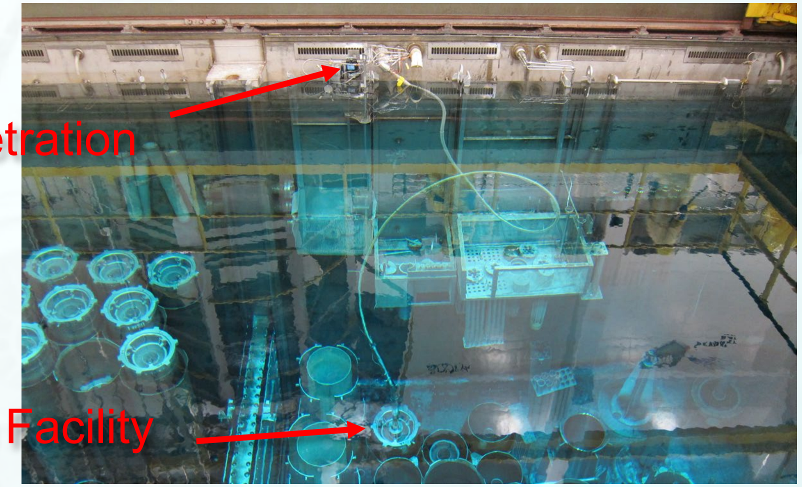
- A series of open-air experiments were conducted to test the gamma thermometer response
- Generally good agreement between analytical model and experimental data at low temperatures
- These tests gave confidence before full assembly of the experiment

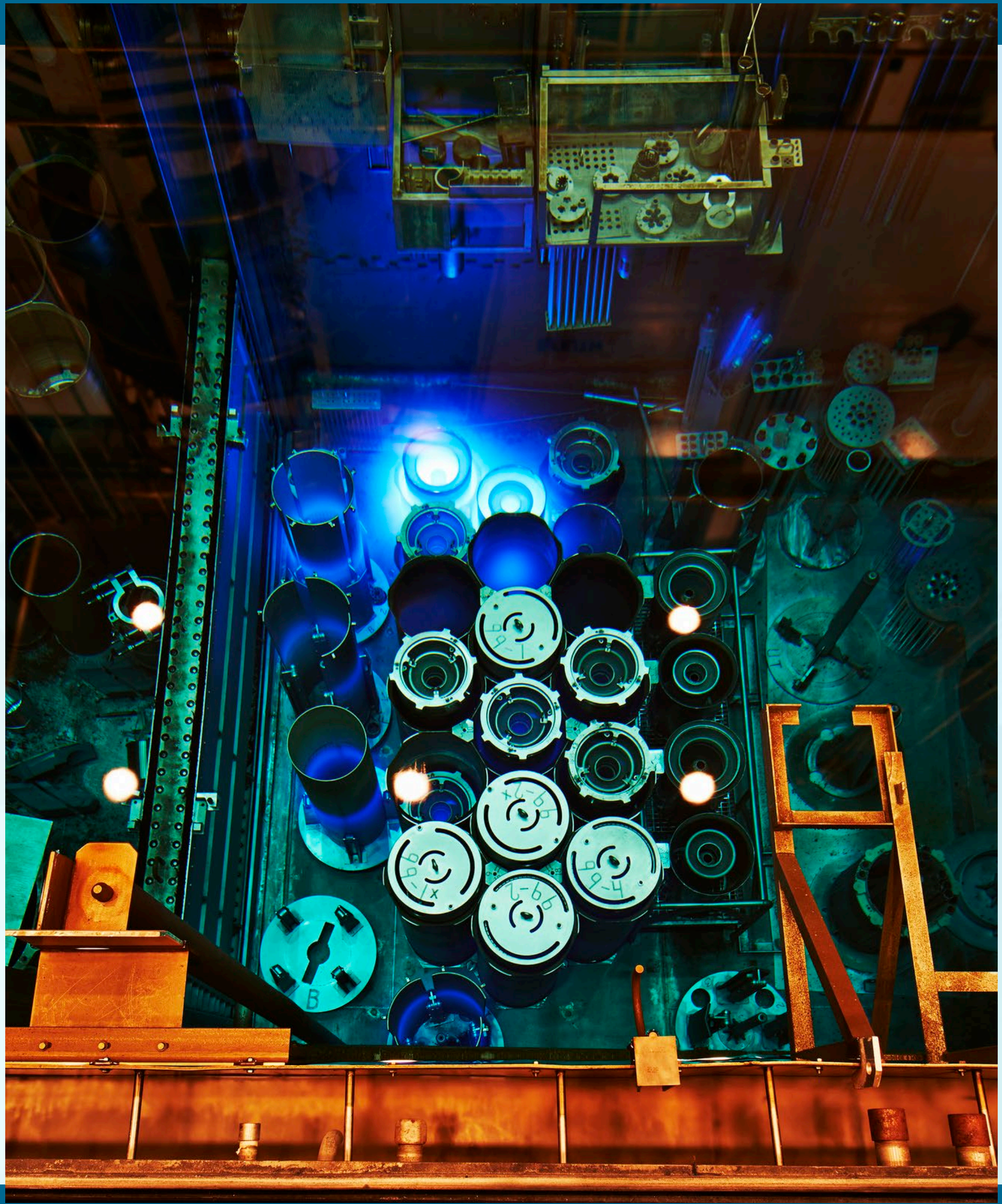




Experimental Plans

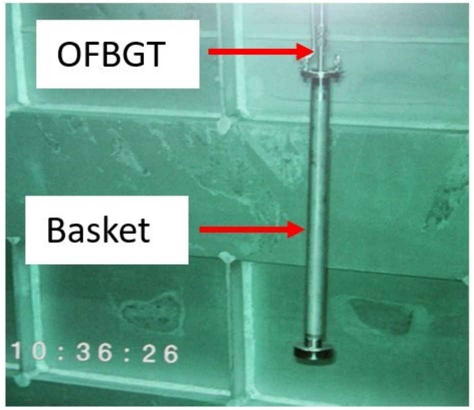
- The plan was to first suspend the OFBGT in the water above the fuel elements and supply a range of currents to calibrate the sensor
  - The water as a surrounding medium will allow steady-state temperatures to be reached in a short period of time (~10 min)
- Then, the OFBGT was inserted into the spent Cycle 501 and Cycle 500 elements
- Temperature was acquired with an OBR-4600
  - Data was interpreted through OFDR



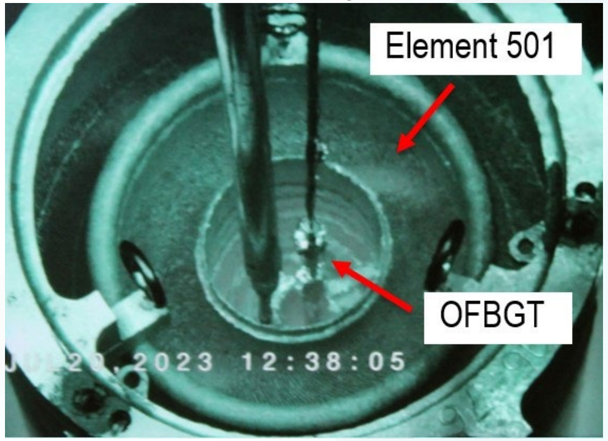


Experimentation Photos

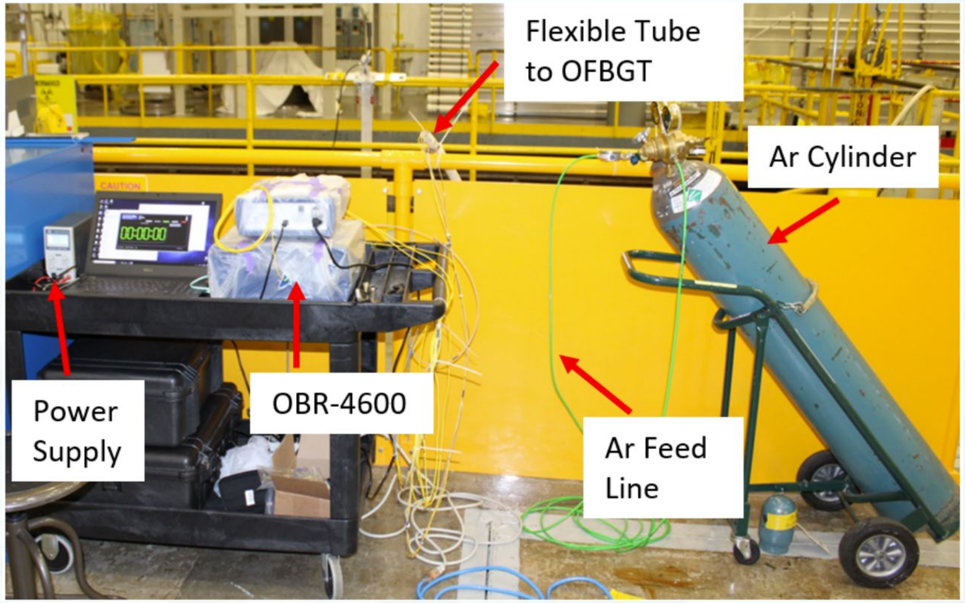
Calibration



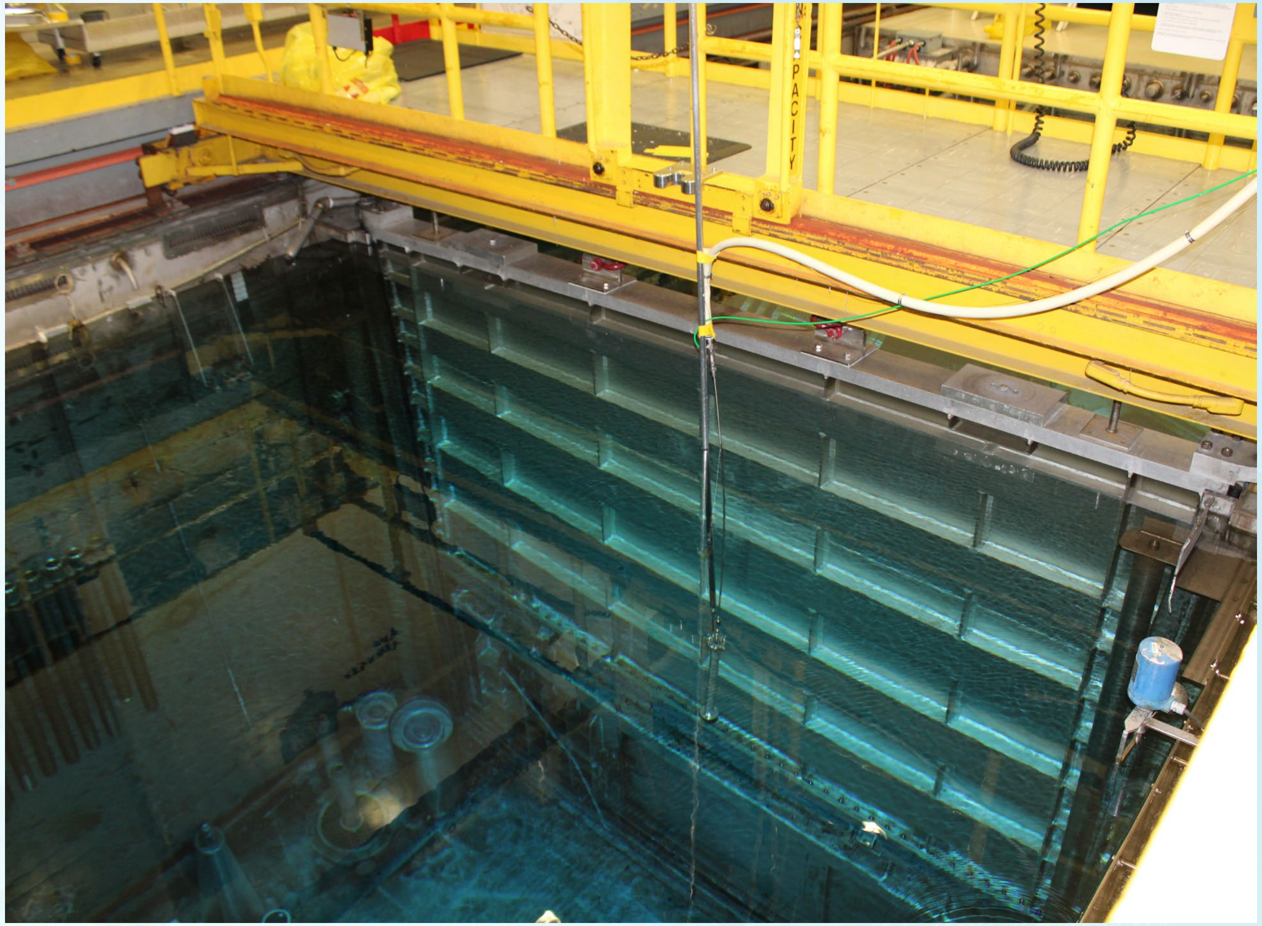
501 Testing



Instrumentation



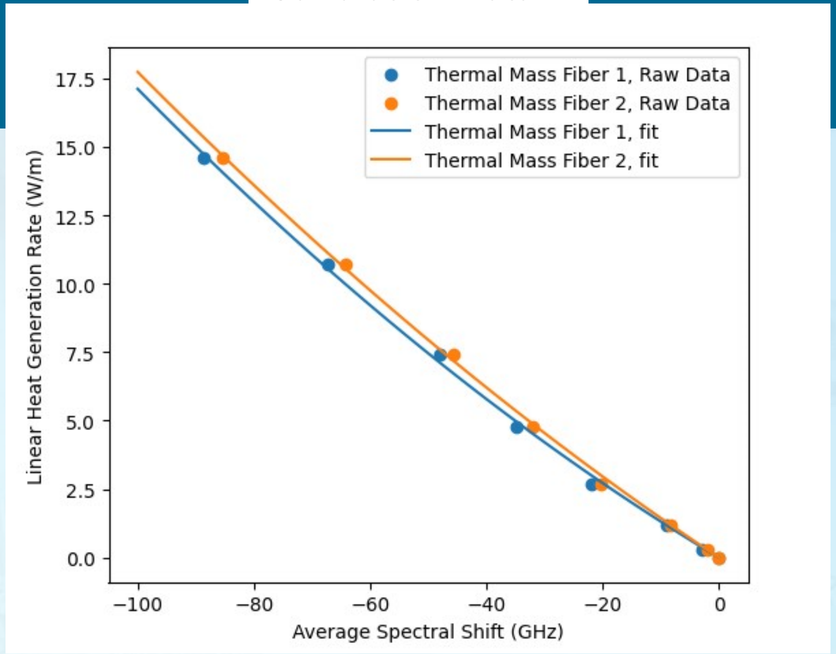
Pool View



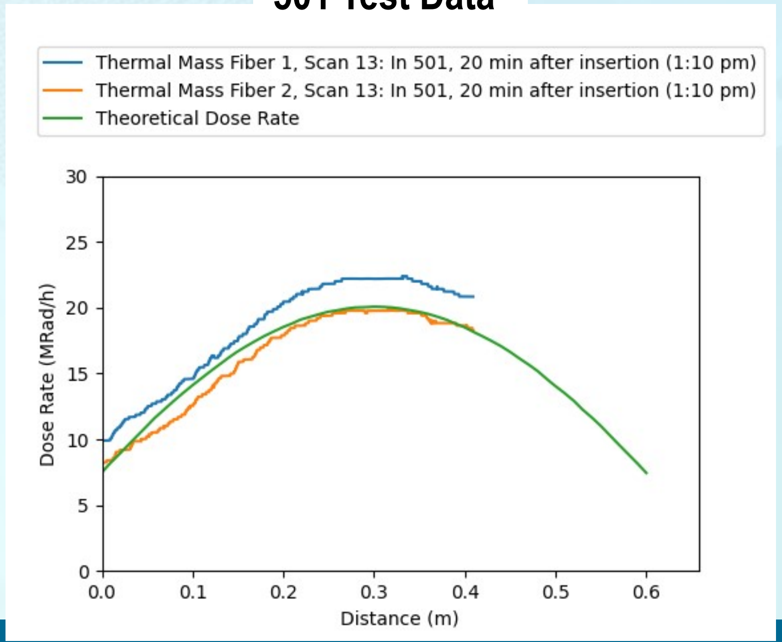
Experimental Results

- Calibration data for each thermal mass fiber differs slightly
  - This is believed to be due to some strain coupling between coating and fiber/insulator
  - Some hysteresis was observed to confirm this notion
  - Calibration curves were then used to convert spectral shift the heating rate/dose rate
- Experimental data shows agreement between theory and experimental data within 10%
  - Theory comes from ORIGEN calculations
  - Fiber to fiber discrepancy due to strain, we believe
  - Slight modulation in the profile likely due to axial heating losses
- General lessons learned:
  - Bare fibers may perform better in future iterations
  - Lower thermal conductivity thermal mass may also help agreement between theory/experiment

Calibration Data



501 Test Data



Concluding Remarks

- ORNL has developed an OFBGT and tested it in the HFIR spent fuel pool
- This work supplements other OFBGT developments by OSU and TAMU, providing additional experiential knowledge
- ORNL is also developing power synthesis methods which allow us to study power inferencing with simulated or experimental sensor data
- The test results confirm that the OFBGT is a viable sensor for distributed sensing of extremely high dose rates
- Future OFBGT designs could be optimized based on lessons learned from this experiment

Acknowledgements:

- This work was directly funded by the ASI Program under the U.S. Department of Energy Office of Nuclear Energy and a NSUF RTE
- Mechanical Design/fabrication support: Kurt Smith, Shay Chapel, Heath McCartney, Bob Sitterson, David Bryant, and Doug Kyle
- HFIR Ops: Dillon Sprague, Nicholas Smith, and Scott Brinkmeier
- Experimental Planning: Richard Howard and N. Dianne Bull Ezell
- Conceptualization: Thomas Blue

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Thank You