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Advanced Sensors and Instrumentation

Status Update on the Gamma Thermometer Irradiation in the HFIR Spent Fuel Pool

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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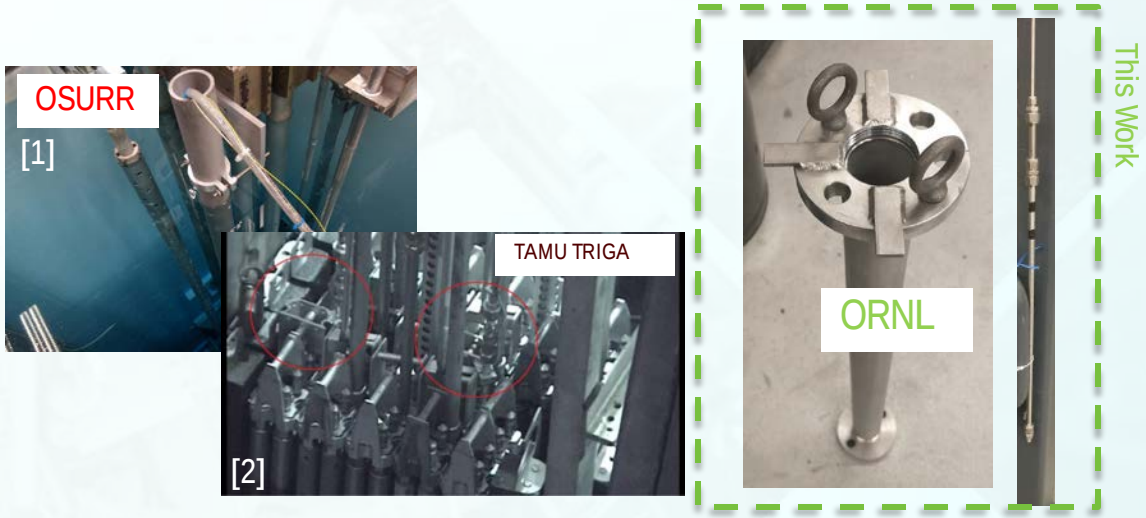
Research Scope

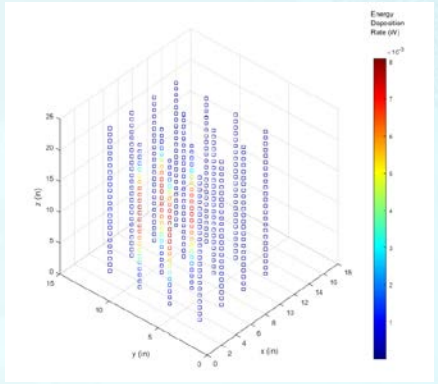
- The goal of this research is to develop, model, and demonstrate an optical fiber-based gamma thermometer (OFBGT) in an intense gamma-ray field
- The irradiations are to occur in the spent fuel pool at HFIR
  - Source of high gamma dose rates
  - Different spent fuel elements can provide different source 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



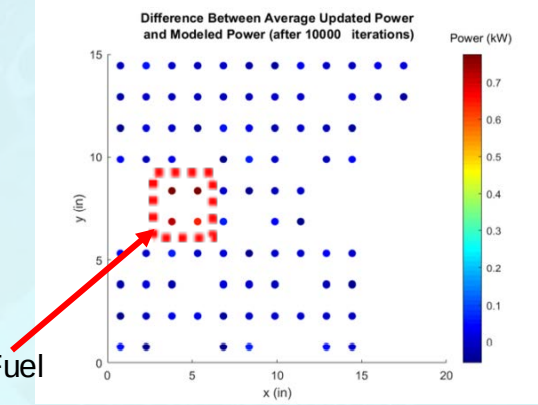
Power Inferencing

Perturbed Sensor Response



Data Analytic Methods

Perturbation Inferencing

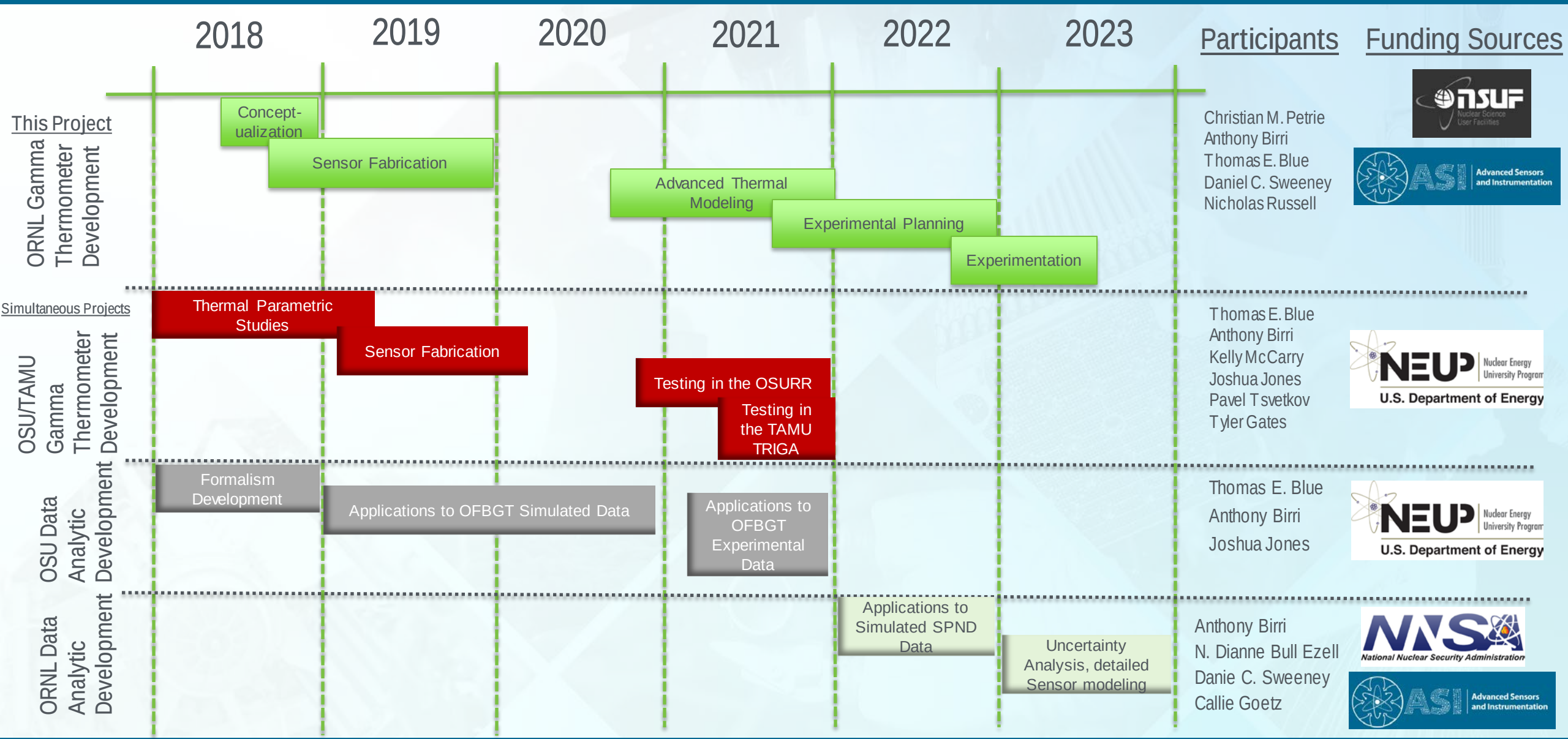


Perturbed Fuel Pins

[1] DOI: osu1626189906070566

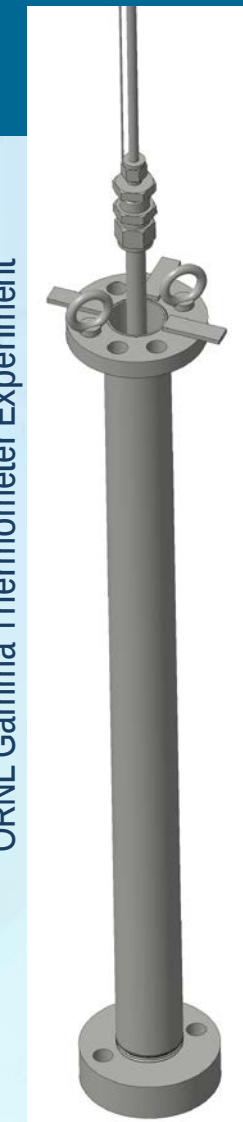
[2] Thesis, Gates T. (2022)

Timeline of this project and other relevant projects

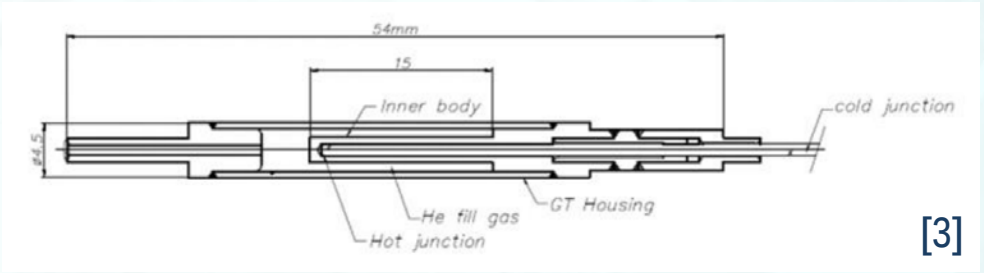


Technology Impact

- 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 measurement of temperature differences between 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

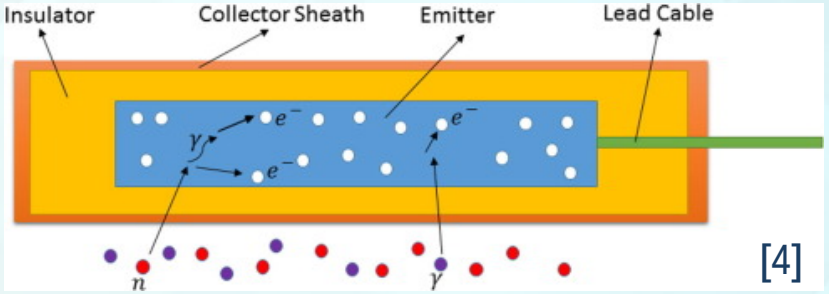


Standard gamma thermometer



[3]

SPND

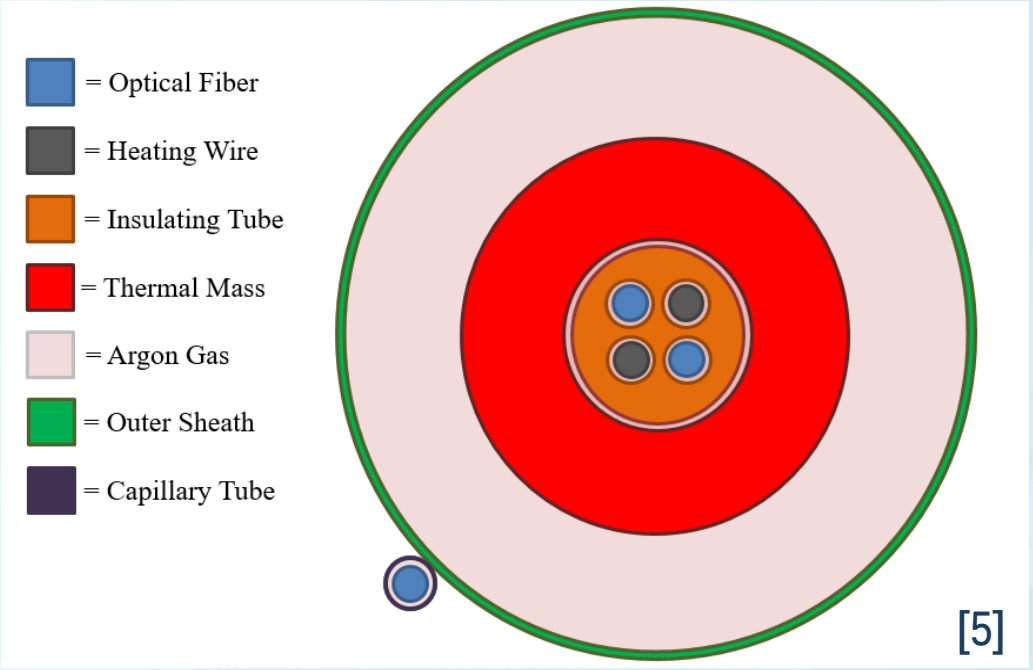


[4]

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

What is a gamma thermometer?

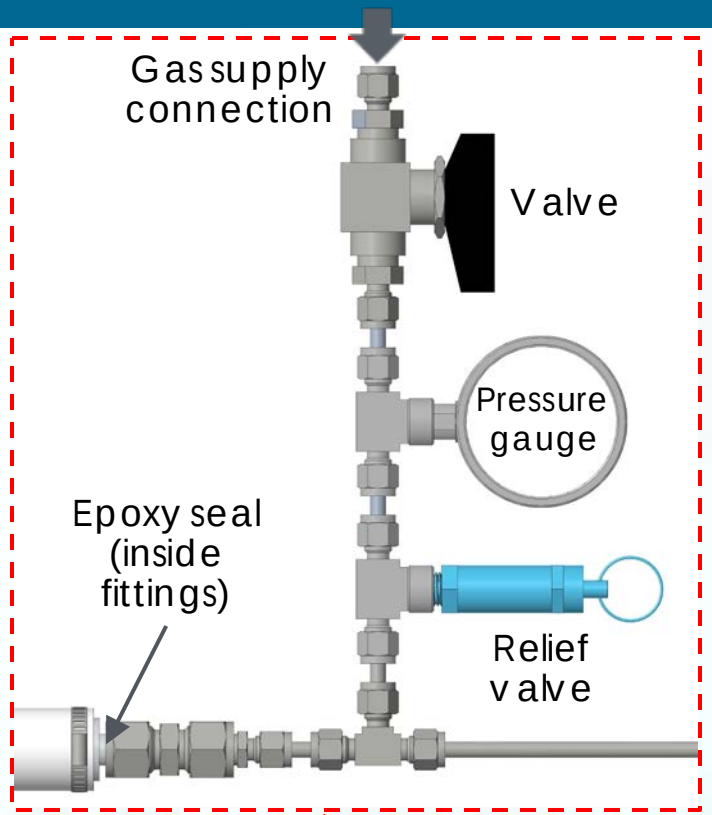
- A gamma thermometer consists of:
  - Thermal mass, in which heat energy is deposited due to gamma rays (q''')
  - Outer sheath, which contains the thermal mass
  - Gas gap, which is responsible for a thermal resistance (R) between the thermal mass and outer sheath, thus resulting in a ΔT ($\Delta T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

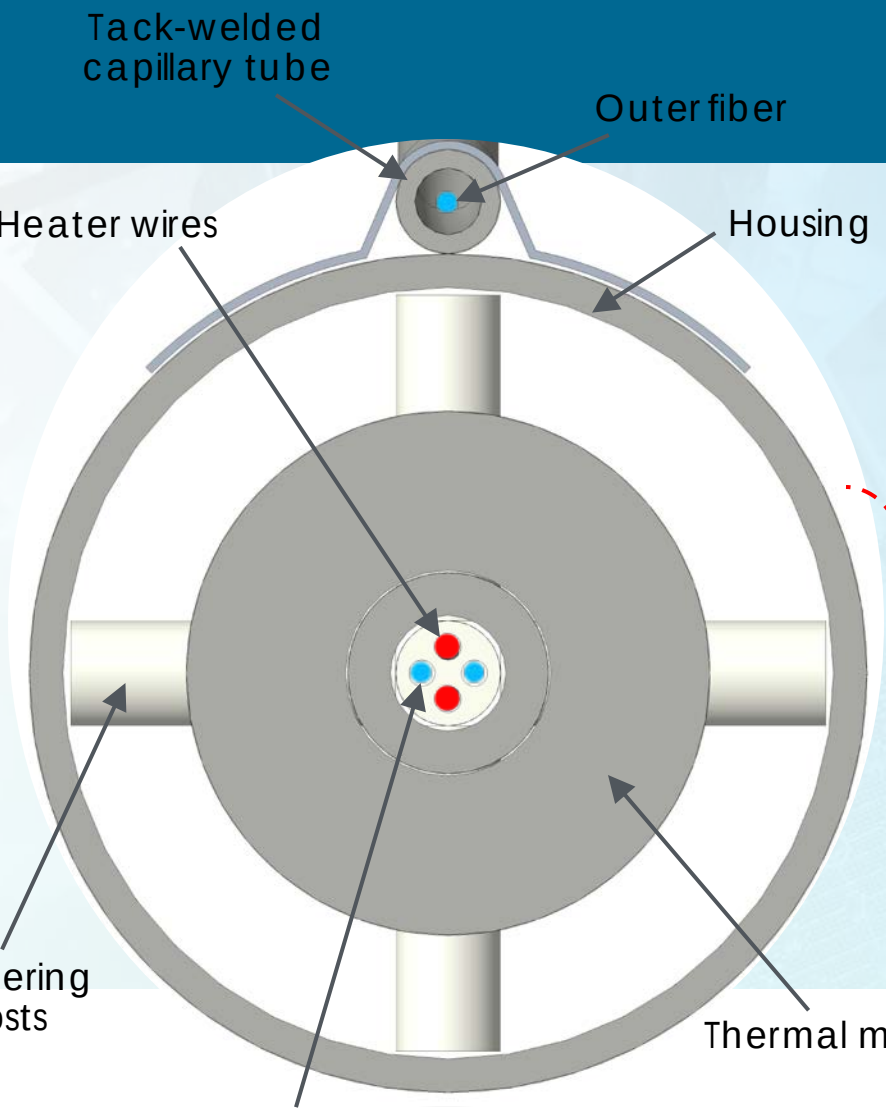


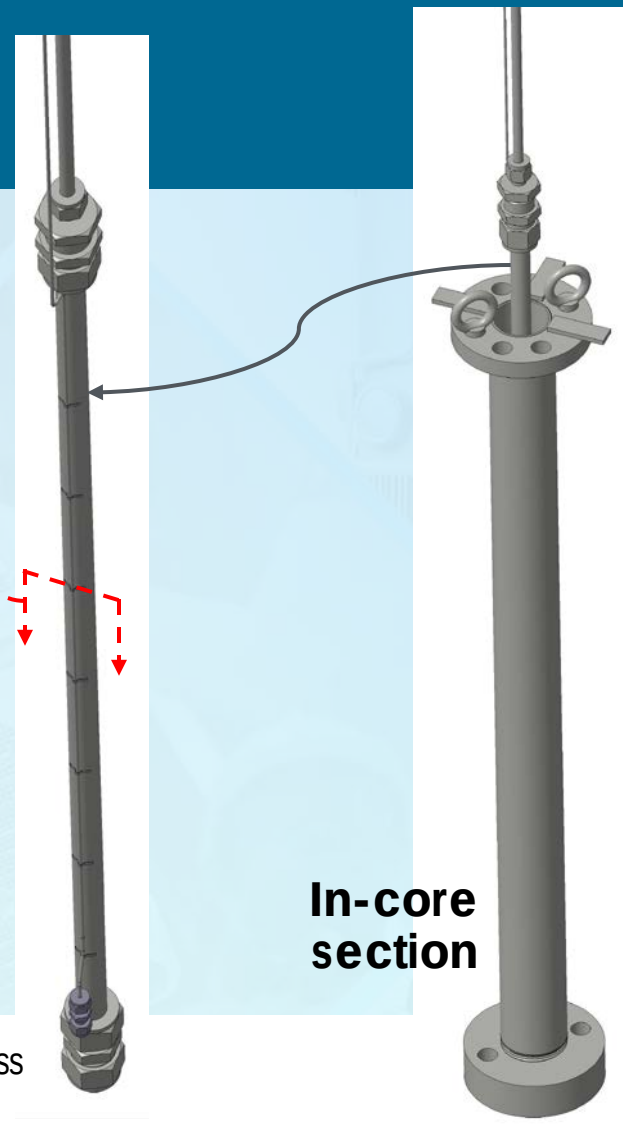
[5]

[5] DOI: 10.1109/JSEN.2020.2978424

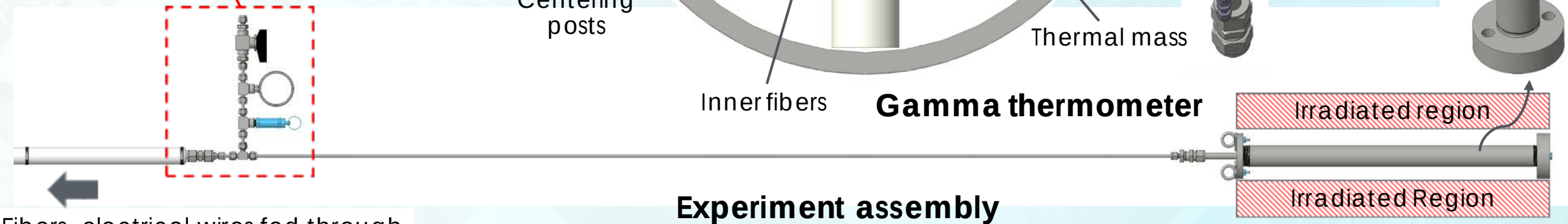
Experiment Design







Gamma thermometer

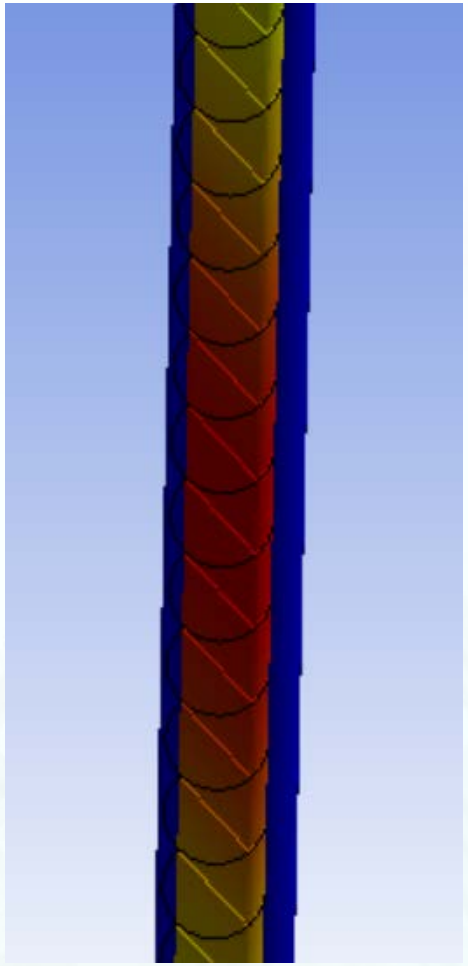


Experiment assembly

Fibers, electrical wires fed through hose to pool top

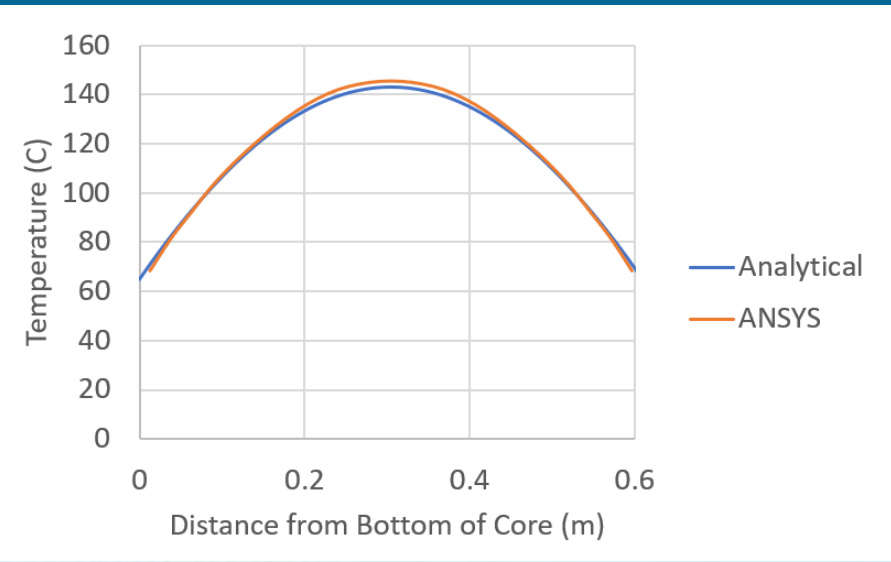
Thermal Modeling Results

ANSYS modeling

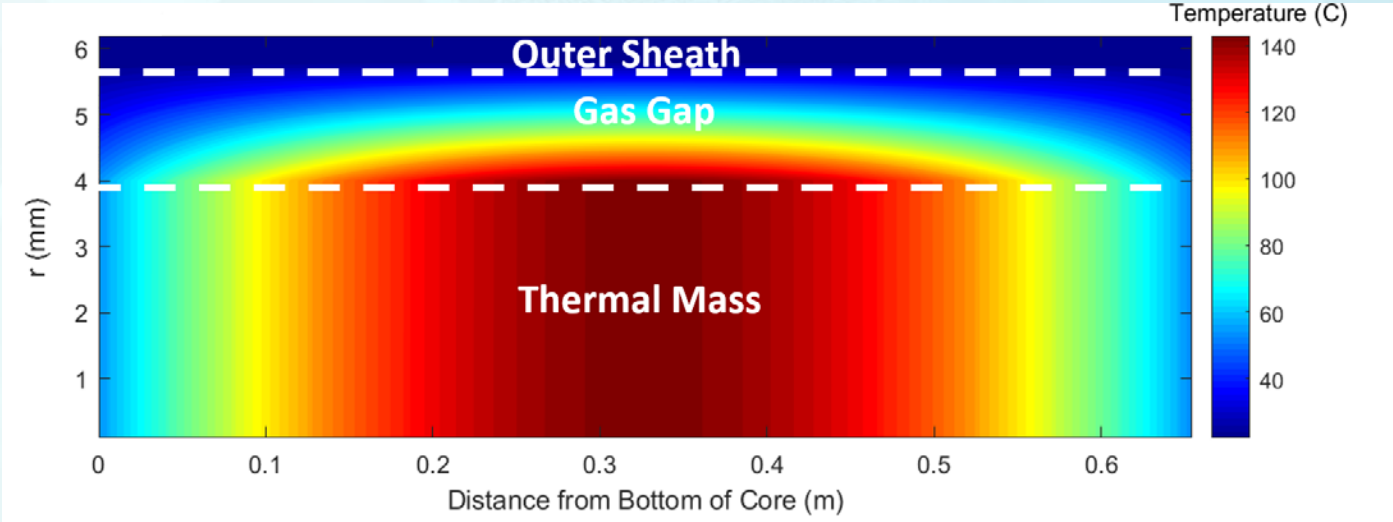


- The ORNL OFBGT has been modeled in ANSYS and analytically to determine the expected temperature profile (10 days from cycle end)
- Temperature depended thermal conductivities considered
- Additional output from this modeling is expected modulation of temperature profile in axial direction

Model verification

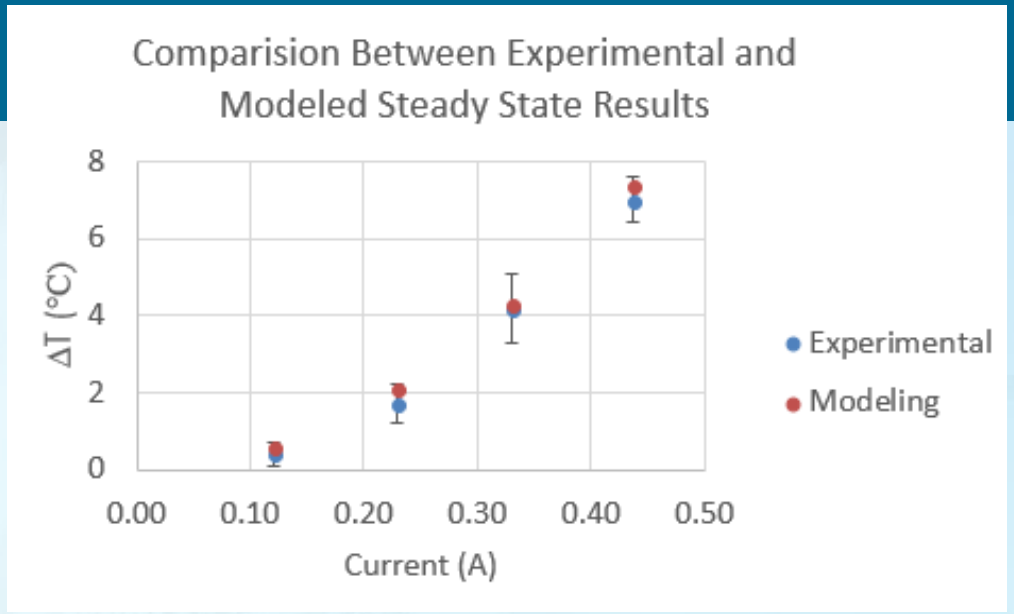


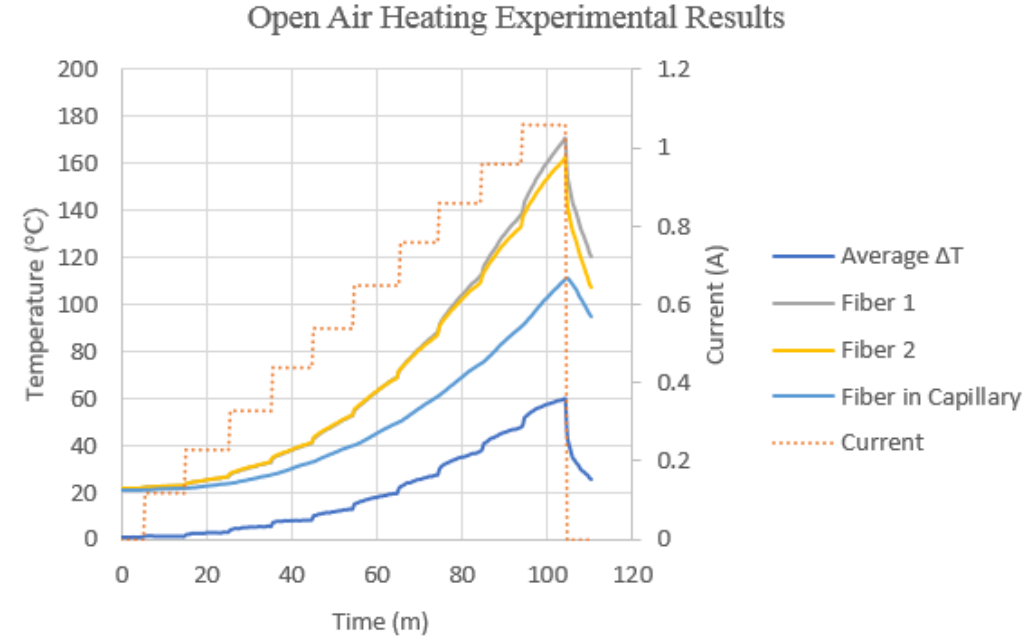
Analytical Model



Preliminary Testing Results

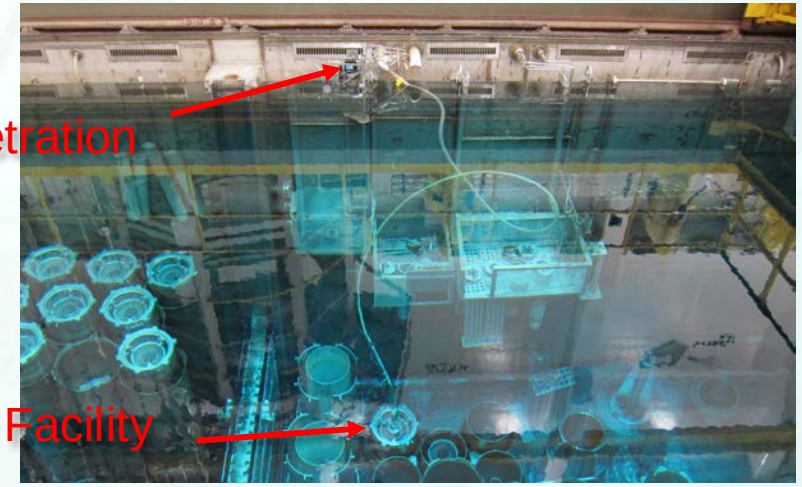
- A series of open-air experiments were conducted to test the gamma thermometer response
- Generally good agreement between analytical model and experimental data at low temperatures
- More steady-state experimental data needed to understand higher temperature performance

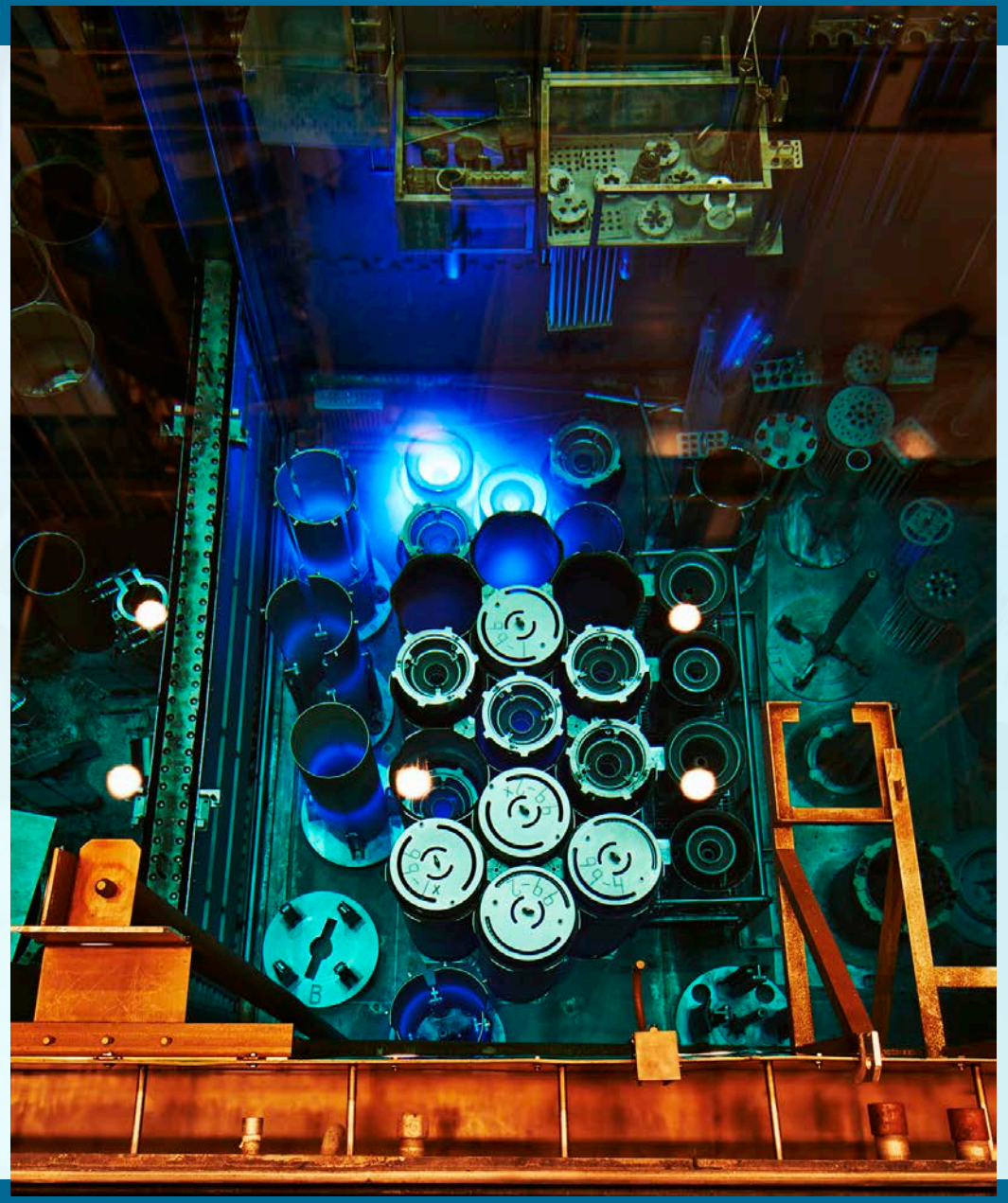




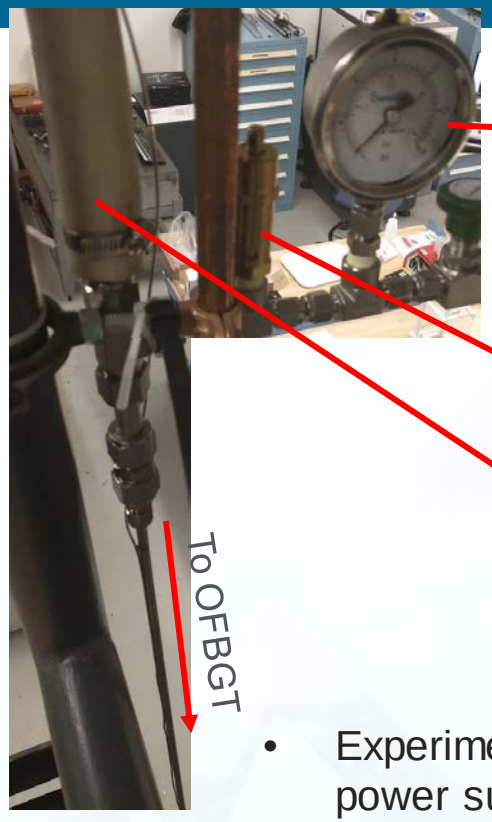
Experimental Plans

- Our plan is 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 will be inserted into the most recently irradiated fuel assembly, as well as 1-2 of the next-most recent
- Temperature data will be acquired with an OBR-4600
- Data can be interpreted in two ways:
  - Tracking of FBG peaks
  - Adaptive cross-correlation methods





Fully Assembled Experiment



Irradiation Basket

Bottom Plugs

- Experiment is fully assembled and ready for plug in to an OBR and power supply
- System has features for pressure monitoring and relief after backfill with argon
- The wires and fibers feed into the steel tube to the OFBGT through a hermetic seal of ultra high vacuum epoxy
- OFBGT will be lowered into a spent fuel assembly in a custom irradiation basket

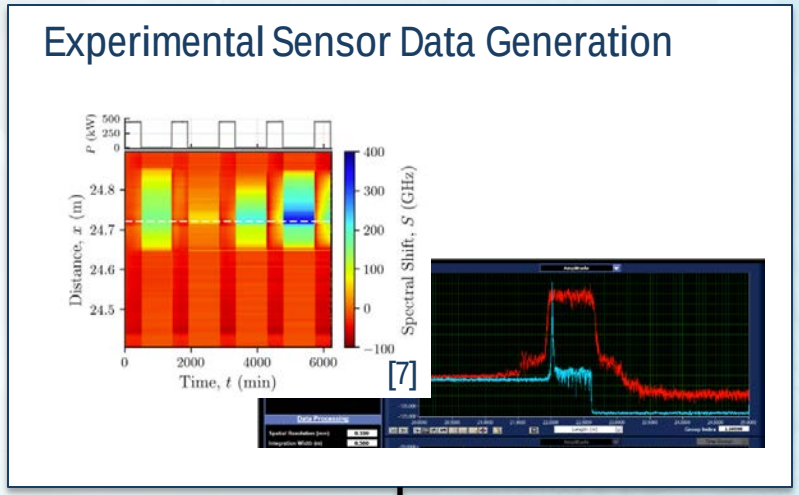
Pre-irradiation Tasks

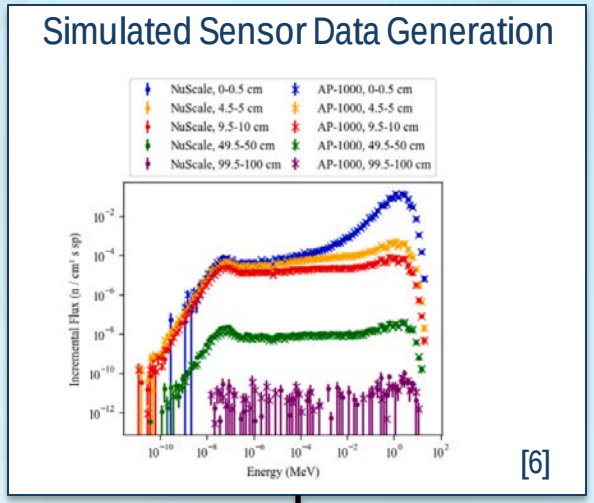
- The OFBGT is essentially ready for experimentation; It has been designed, modeled, and benchtop tested
- However, we need to abide by HFIR QA practices and documentation protocols before irradiation
- Pre-irradiation task list is as follows:

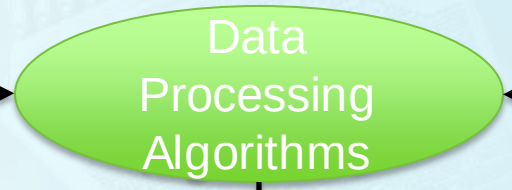
1. Generate appropriate documentation that establish QA requirements, handle exceptions, describe procedures ✓
2. Ensure that optical/electrical lead-ins are of the appropriate lengths ✓
3. Establish backfilling plans and cleaning requirements ✓
4. Qualify and document all parts on the OFBGT, obtain signatures on all other documentation ⏳
5. Schedule official irradiation date
6. Transport OFBGT to HFIR
7. Set up experiment with interrogation equipment

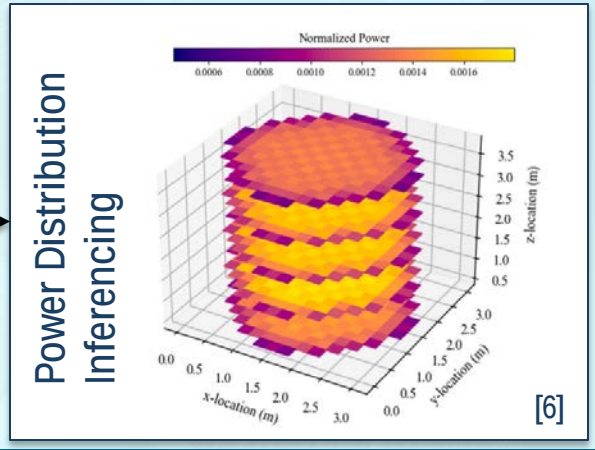
ASI Project Symbiosis

- The experimental work we are doing with the OFBGT is a piece of a larger overall picture
  - This work represents an effort in experimental in situ sensor data generation
  - ORNL is also working on simulated sensor data generation, and power inferencing techniques
- Gaining experience on the data generation and processing sides of the picture provides unique insight:
  - Realistic idea of sensor uncertainty
  - How many sensors do we really need in the core
  - How do reactor core conditions impact sensor performance
- Going forward, ORNL hopes to support the ASI program on both the in situ sensor data generation and data processing fronts









[6] DOI: 10.1016/j.pnucene.2022.104437

[7] DOI: 10.1109/JSEN.2020.3013121

Concluding Remarks

- ORNL has developed an OFBGT and will be testing 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 data analytic methods which allow us to study power inferencing with simulated or experimental sensor data
- ORNL will continue to work with HFIR to get the experiment completed as fast as possible, without compromising safety or QA
- ORNL will also continue to support the ASI program through continued investigation of data analytic methods

Acknowledgements:

- This work is directly funded by the Advanced Sensors and Instrumentation (ASI) Program under the U.S. Department of Energy Office of Nuclear Energy.
- Dr. Thomas E. Blue for playing a large role in the conceptualization of the ORNL gamma thermometer design
- Daniel C. Sweeney and Nicholas Russell for fabrication
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Thank You