High Resolution Reactor Power Profiling with Optical Fiber-Based Gamma Thermometers

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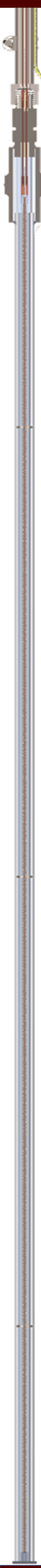
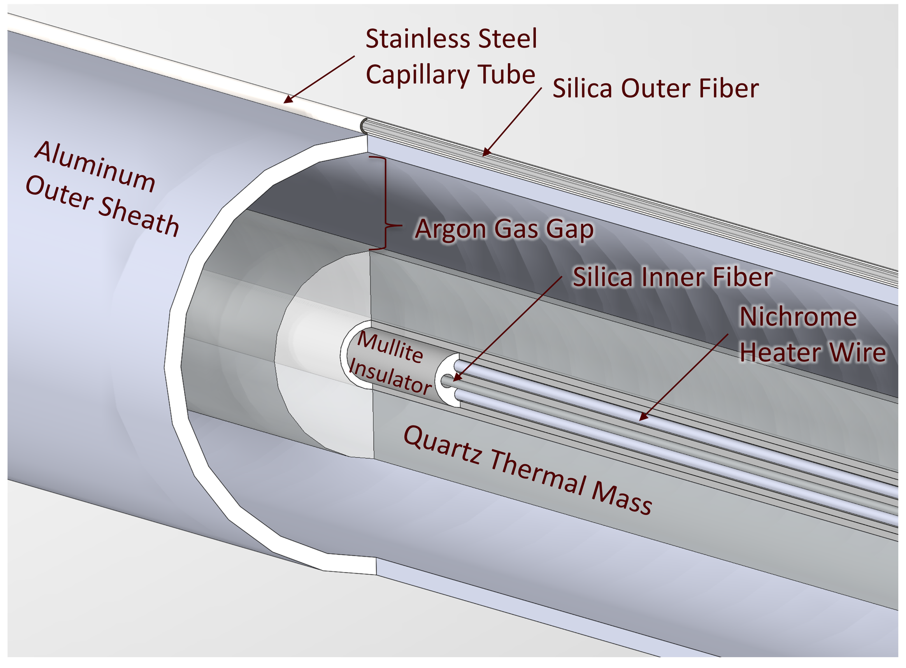
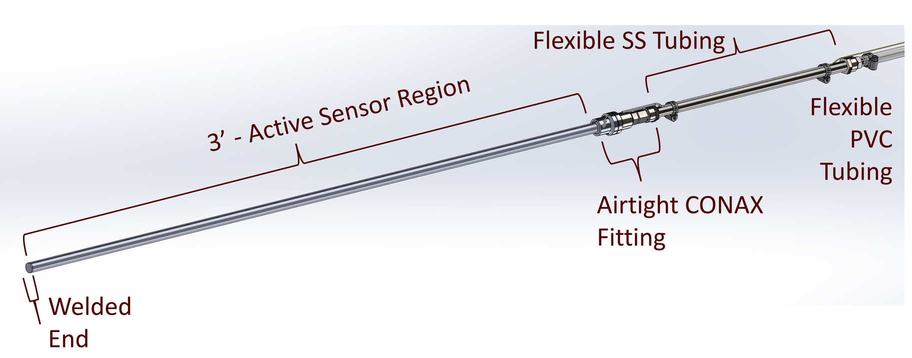
NEUP Nuclear Energy University Program
U.S. Department of Energy







Overview

Optical Fiber Based Gamma Thermometers (OFBGTs) were:

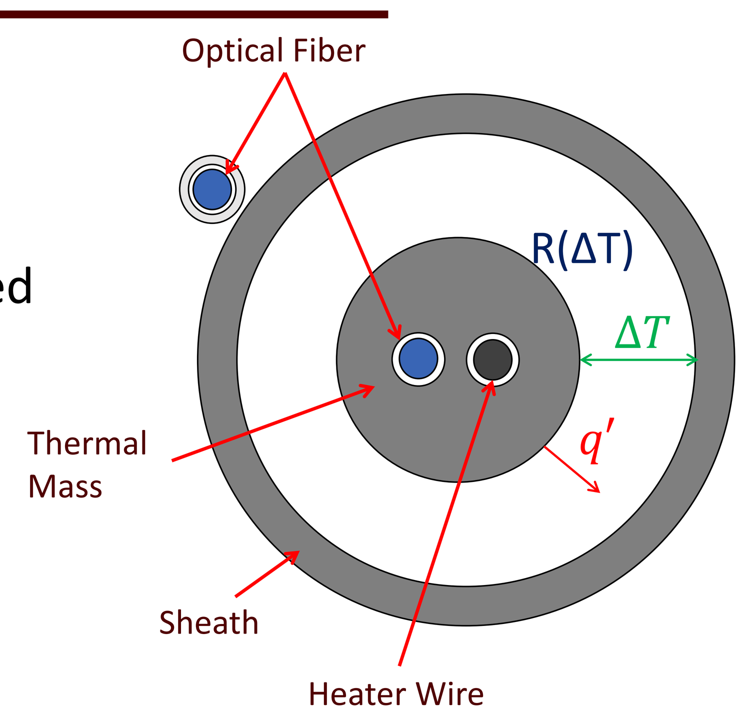
- ✓ Designed
- ✓ Constructed
- ✓ Tested in Texas A&M TRIGA and OSURR
  - ✓ 9 Locations Tested within TRIGA Core

Optical Fiber Based Gamma Thermometers (OFBGTs) Promise:

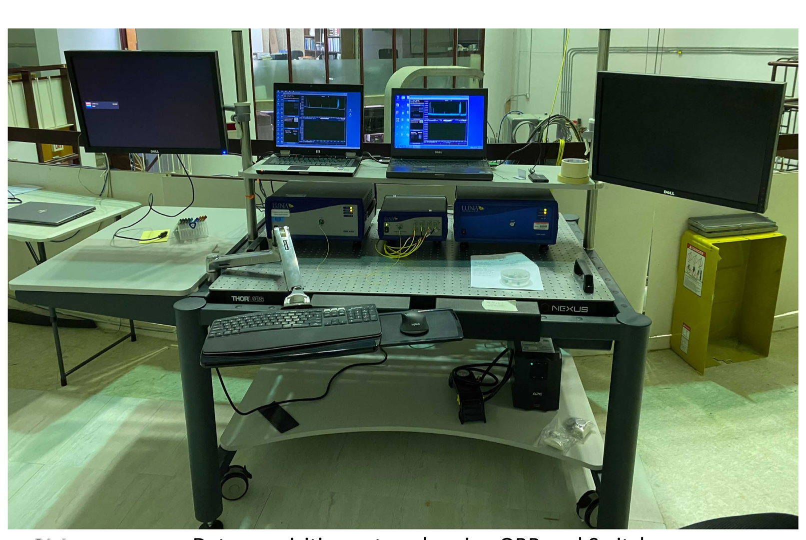
- ✓ Improved Resolution compared to Traversing In-Core Probes (TIPs)
- ✓ Fixed in-core placement
- ✓ Simultaneous Measurement of Gamma Flux and coolant temperature

OFBGT Design and Function

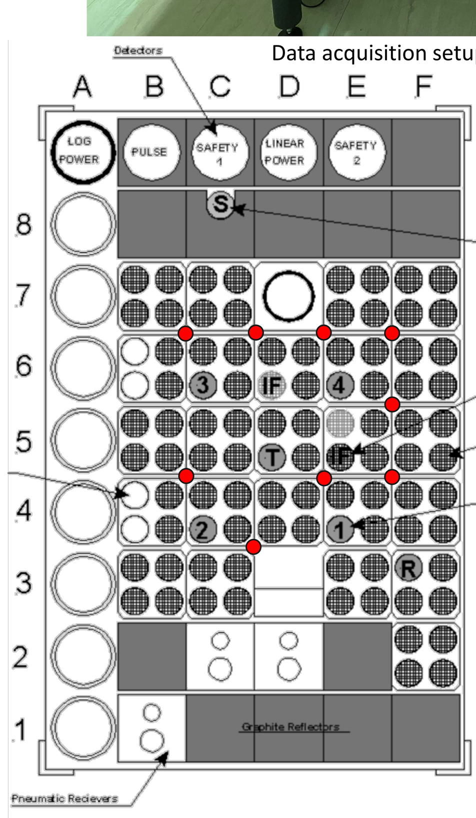
- Gamma Sensitive Thermal Mass
- Temperature of Thermal Mass Measured
  - Inner Fiber measures axial $T_i(z)$
- Temperature at outside of sensor measured
  - Outer Fiber measures axial $T_o(z)$
- Response function relates q' to $\Delta T(z)$
  - $q'(z) = R(\Delta T)$
  - Heater wires for calibration



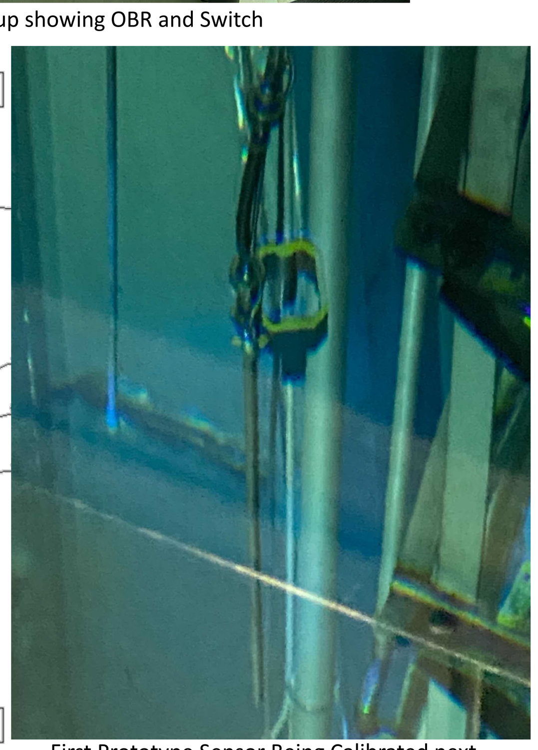
Testing in Texas A&M TRIGA Reactor



Data acquisition setup showing OBR and Switch



Sensor Locations Tested in Exp. 3



First Prototype Sensor Being Calibrated next to TRIGA Pool Thermocouple

Experiment 1:

- Tested Sensor Insertion and Removal
- Qualification Tests for full-power operation
- Data informed iterative design improvements

Experiment 2:

- Test prototype sensors in nominal operating conditions (400-900 kW)
- Testing ended early due to sensor failures
- Data informed iterative design improvements

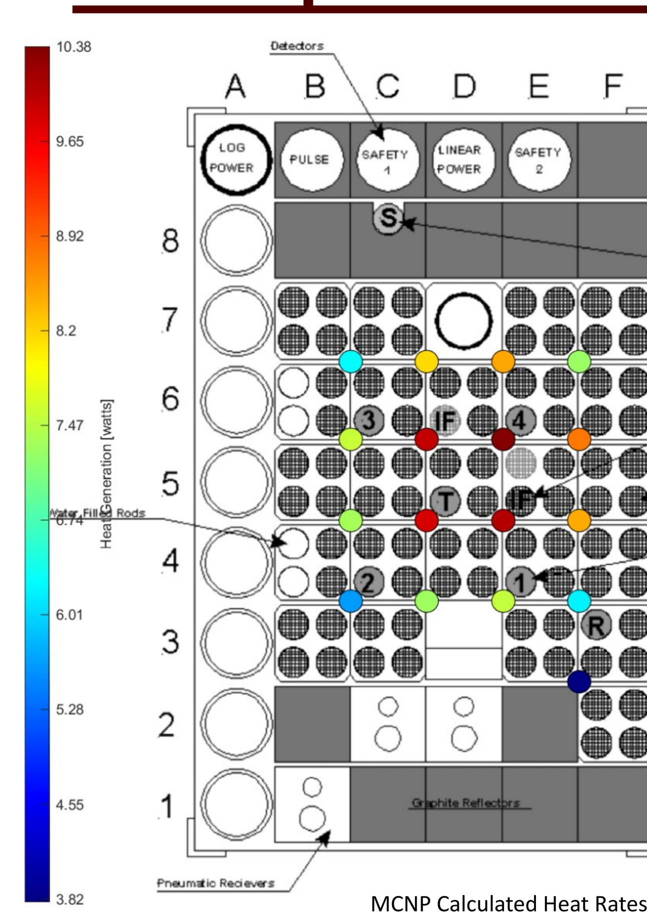
Experiment 3:

- Rebuilt prototypes tested in nominal operating conditions (400-900 kW)
- Testing successful in 9 sensor locations
- Data used to inform power reconstruction algorithms
- Experience used to inform high-temperature sensor design

Conclusions and Future Work

- Several prototype sensors were constructed and tested in the Texas A&M TRIGA Reactor
- Prototype OFBGTS performed as expected
- Reliability issues are typical among prototypes and could be solved through the commercialization process
- Future Work needed in 5 Areas:
  1. Sensor Reliability – iterative design improvements and quality control
  2. Vibrations – Hardware and Software solutions
  3. High Temperature and High-Fluence Environments – advanced materials
  4. Data Reconstruction – reduce dependence on models and improve resolution
  5. System Longevity – address long-term performance and maintainability

Computer Simulated Performance



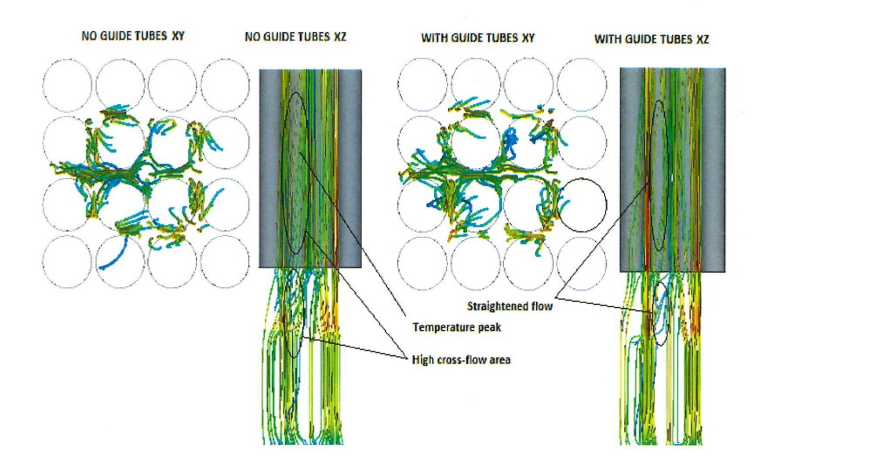
MCNP Calculated Heat Rates

MCNP-Generated Photon and Neutron Heating Rates

- 17 Sensor Locations
- Heat Generation Ranges from 3.82 W to 10.38 W
- 90% of heat generated by Photons

Leveraged Previous Thermal-Hydraulic Analysis for Similar Sensors:

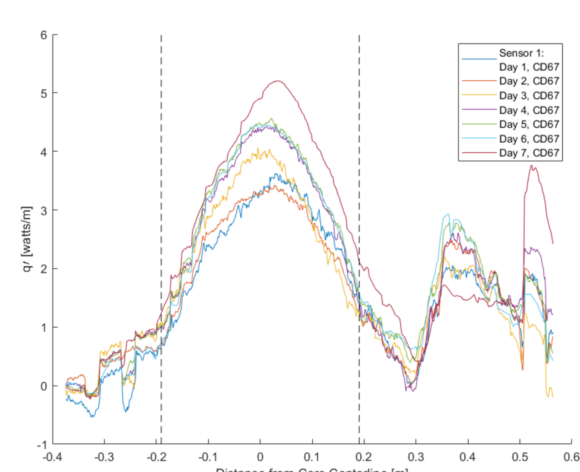
- Predicted straightened flow, higher flow rates, and cooler fuel temperatures



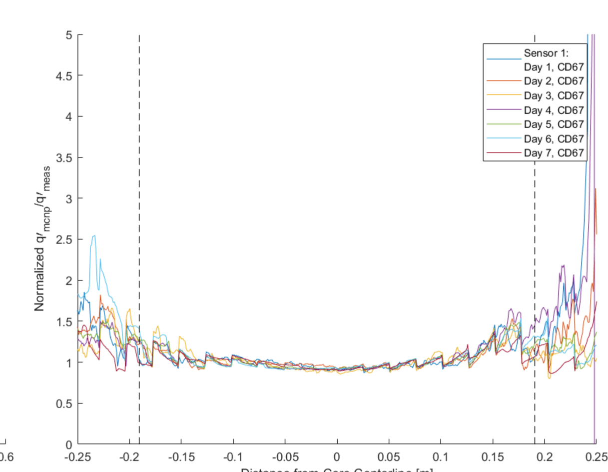
CFD Calculations for sensors with identical geometry to OFBGTs

Results

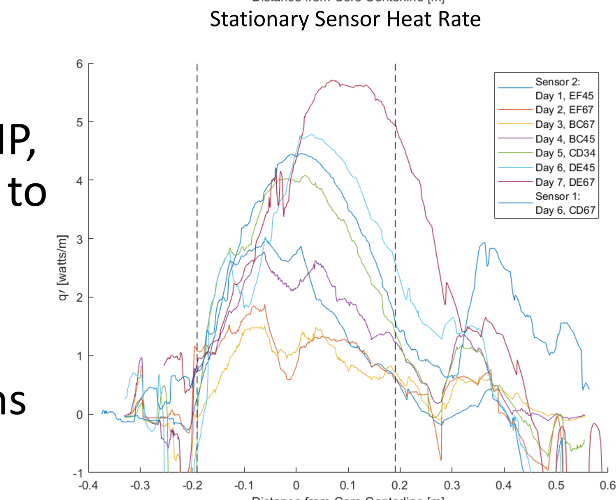
- Heat rate consistent for individual positions
- Shape of heat rate unique to each position
- Heat rate is more accurate near center of the core, has more variability at edges
- Data agrees well with MCNP, with some differences due to vibrations and noise
- The desired data was obtained, but room remains for improvements



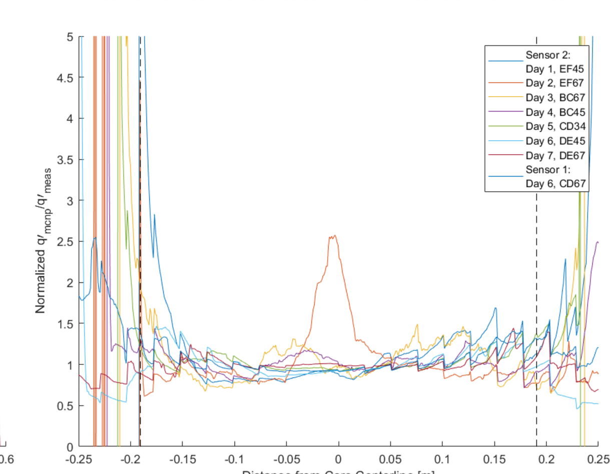
Stationary Sensor Heat Rate



Ratio of MCNP Heat Rate to Measured Heat Rate



Moving Sensor Heat Rate

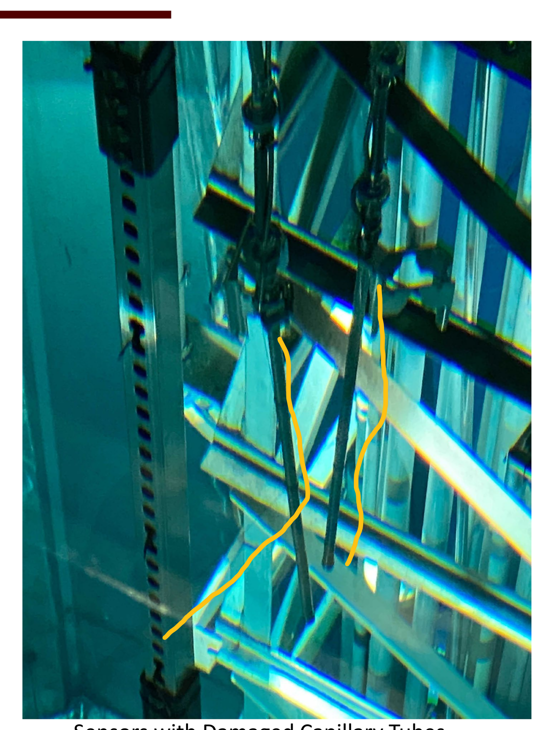


Ratio of MCNP Heat Rate to Measured Heat Rate

Lessons Learned

LEAD TO

- **Sensor Design and Reliability**
  - Solder failure in Experiment 1
  - Solder Rings and Epoxy failure during Experiment 2
    - Soldered rings snagged on insertion
    - Capillary Tube fibers damaged as a result
  - Sensor bending during experiment 3
    - Thin tubing bent during insertion
  - Other minor ease-of-use issues
- **Vibrations and Flow Effects**
  - Sensor vibrations in core due to flow
  - Building vibrations impacting optical equipment



Sensors with Damaged Capillary Tubes

Iterative Improvements

Repaired Sensors with Mechanical Fasteners

- **Sensor Design and Reliability**
  - Several methods of attaching Capillary Tubes to outer sheath Eventually resorted to mechanical fasteners
  - Improved construction quality control
  - Improved in-core support mechanisms
- **Vibrations and Flow Effects**
  - Made use of passive-isolation optical table for OBR
  - Reduced cross flow over the core by controlling pumps.
  - Increased scan rate to mitigate vibration effects

Acknowledgments

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