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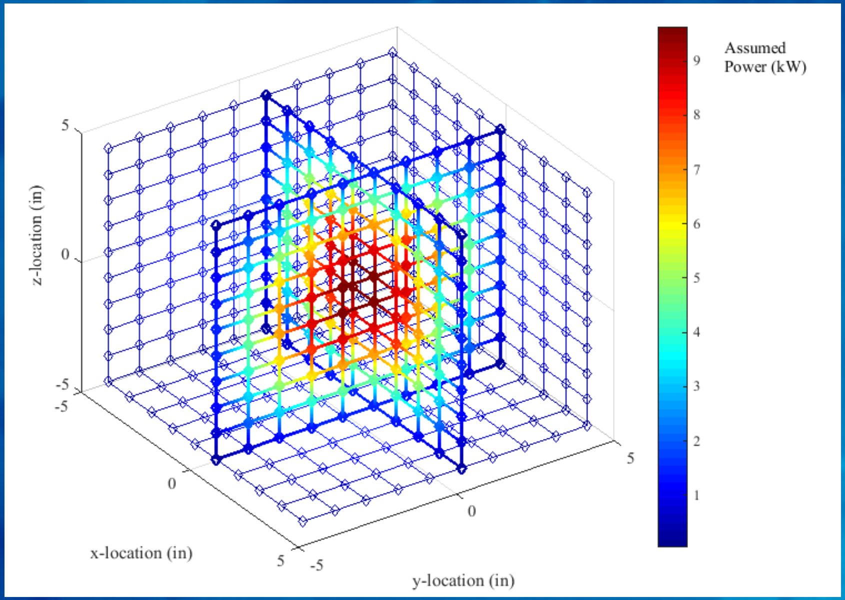
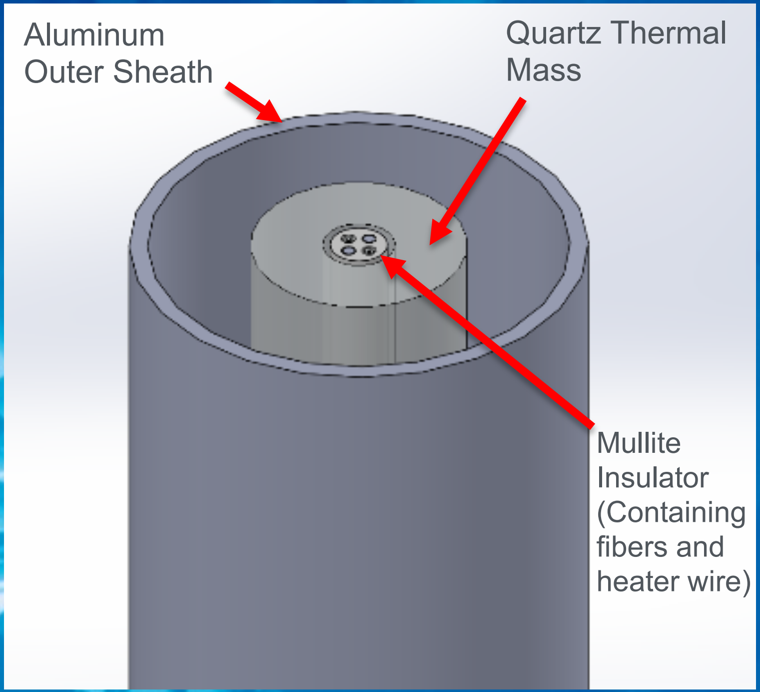
Development of an Optical Fiber Based Gamma Thermometer





Advanced Sensors and Instrumentation Annual Webinar

November 6, 2019

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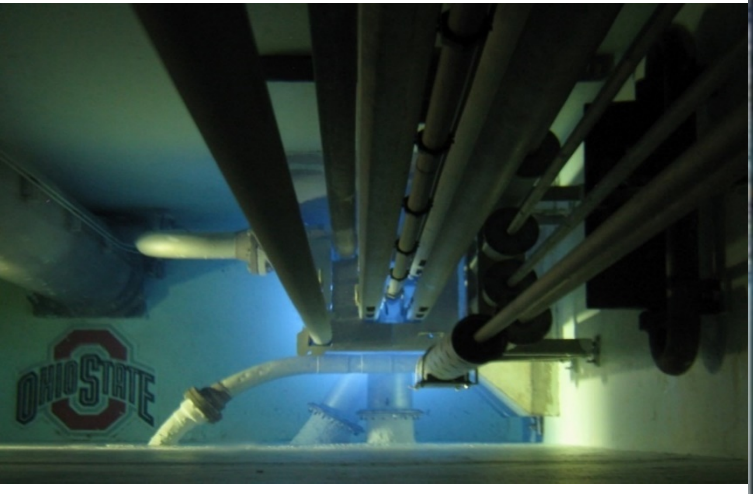
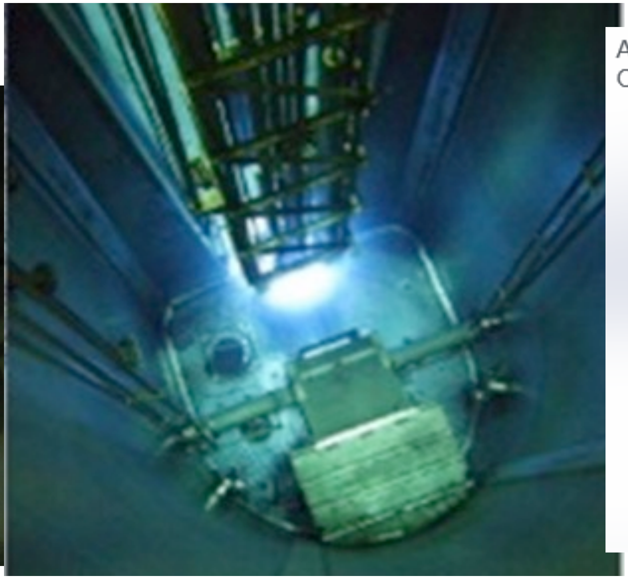
Objective

- Develop an optical fiber based gamma thermometer (OFBGT) in order to determine the power distribution in a reactor core by using statistical data analytic methods
  - An OFBGT measures the ΔT along the axial length of the sensor which can be used to infer core power distribution using response functions generated by MCNP (ΔT is measured by optical fiber)
  - We plan to demonstrate this measurement technique in both the Ohio State University Research Reactor (OSURR) and the Texas A&M TRIGA Reactor
- Participants: The Ohio State University, Texas A&M University, INL

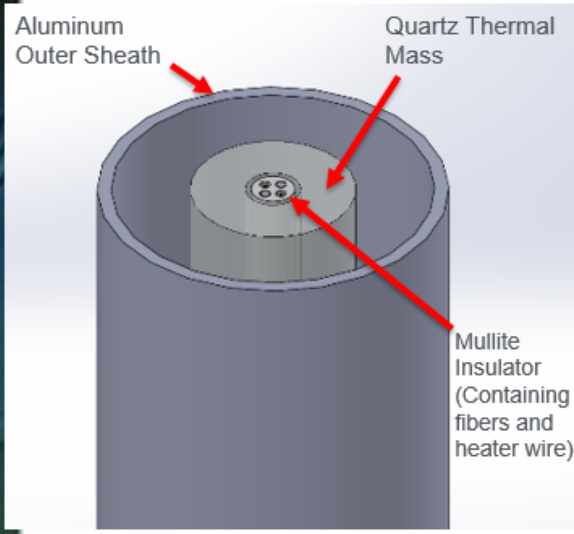
OSURR



TAMU TRIGA



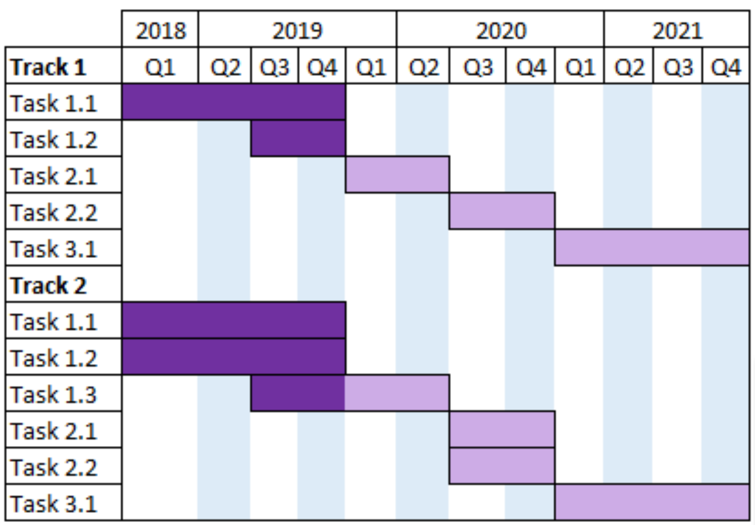
OFBGT



Schedule

- Track 1: Build OFBGTs and test them in a University Research Reactor
  - Year 1
    - Task 1.1: Design OFBGTs
    - Task 1.2: Design and build irradiation test rigs
  - Year 2
    - Task 2.1: Construct OFBGTs
    - Task 2.2: Test OFBGTs with silica fiber in OSURR and TAMURR
  - Year 3
    - Task 3.1: Repeat Tasks 2.1 and 2.2 for OFBGTs with sapphire fiber

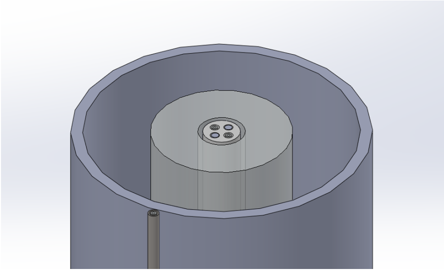
- Track 2: Modeling and Data Analytics
  - Year 1
    - Task 1.1: Create modeled(MCNP and ANSYS) OFBGT data for irradiation facilities
    - Task 1.2: Develop methods and algorithms to process OFBGT data using modeled data
    - Task 1.3: Apply data analysis methods to MCNP OFBGT data to predict power distributions
  - Year 2
    - Task 2.1: Apply data analysis methods to test data for OFBGT with silica fiber
    - Task 2.2: Refine the models and data analysis methods
  - Year 3
    - Task 3.1 Repeat Tasks 2.1and 2.2 for data for OFBGTs with sapphire

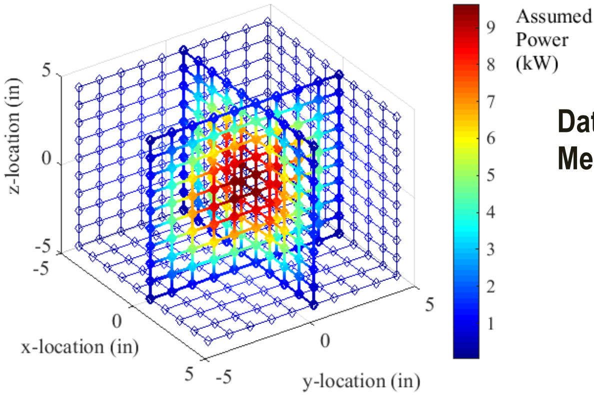


Accomplishments

- Completed the final OFBGT design
  - The final design has optimal thermal characteristics for research reactor, consists of orderable parts, and will not have significant neutron activation
  - Satisfies deliverables for Track 1, Task 1.1 and Task 1.2
- Developed data analytic methods to process OFBGT data
  - Utilizes an energy balance method which is informed by modeled data (MCNP) and measured data
  - Satisfies deliverable for Track 2, Task 1.1
- Generated modeled data of the OFBGT
  - OFBGT within the OSURR (MCNP)
  - Thermal modeling (ANSYS, custom analytical model)
  - Satisfies deliverable for Track 2, Task 1.2

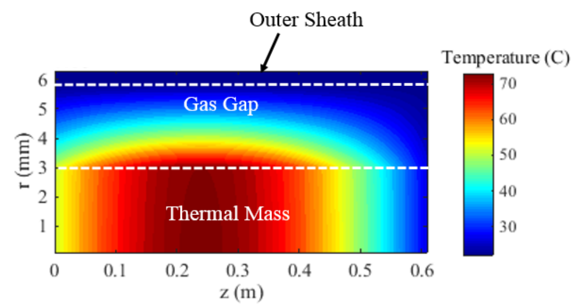
OFBGT Design





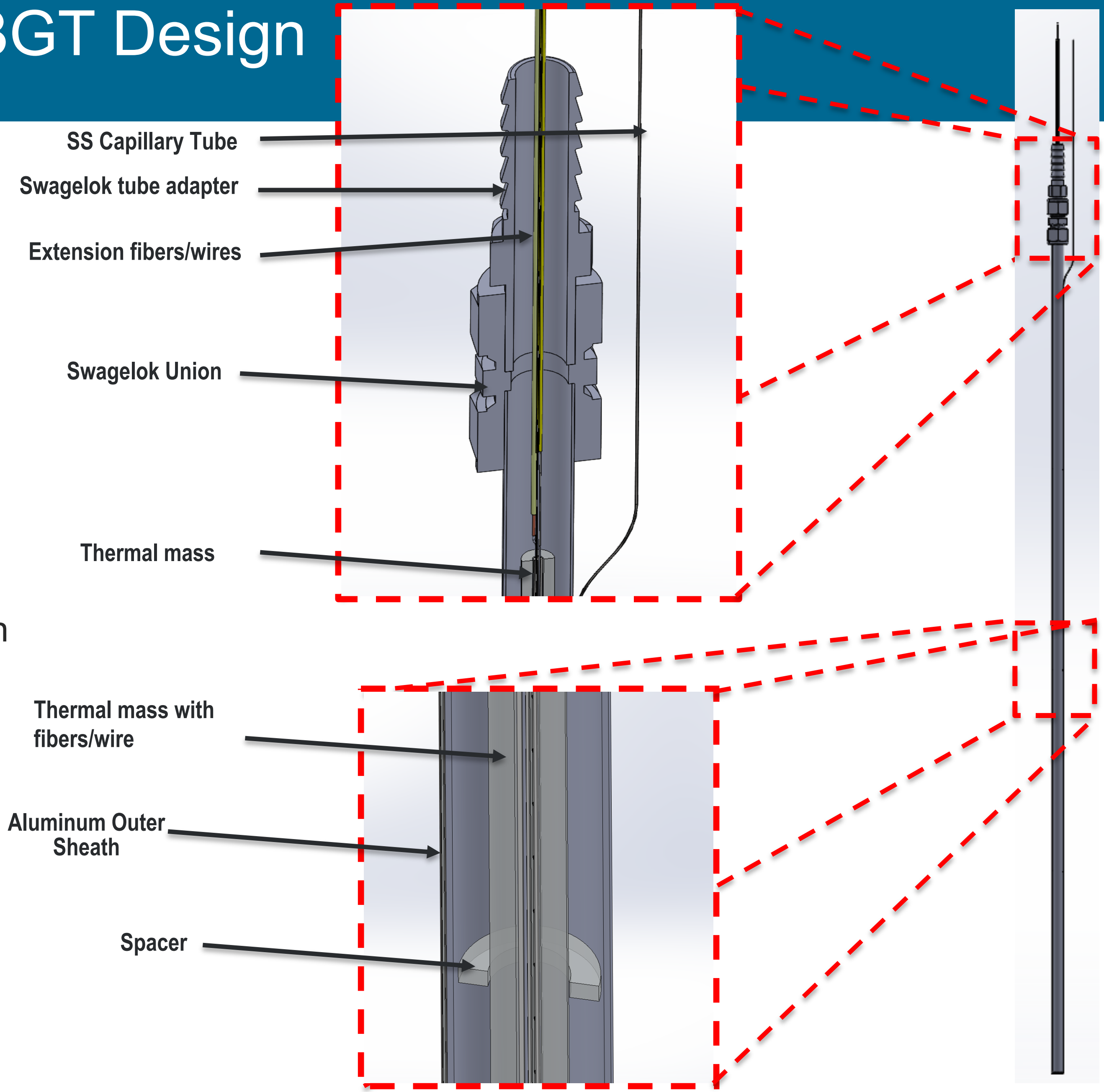
Data Analytic Methods

Thermal Modeling



Finalized OFBGT Design

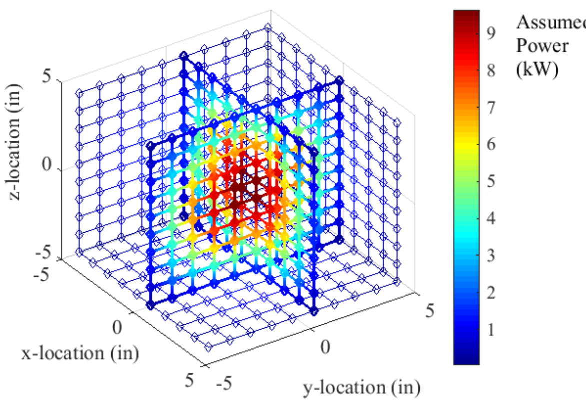
- Quartz Glass Thermal Mass due to low thermal conductivity
- Mullite insulating tube to hold fibers and nichrome wire
  - Fibers have Type II FBGs
  - Nichrome heating wire for calibration
- Glass Spacers
- Aluminum outer sheath
- Stainless steel capillary for outer fiber
  - Due to small size, activation should be within limits
- Swagelok junction to flexible tubing
- Outer sheath OD: ½”
- OFBGT length: 3 ft

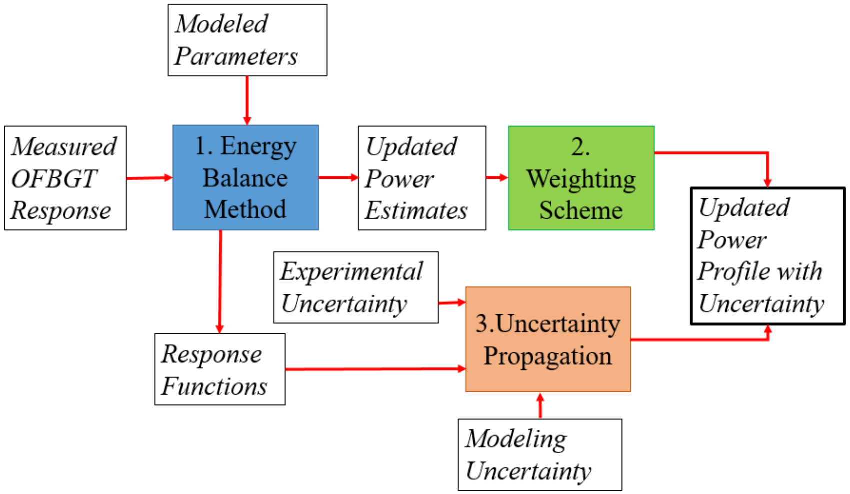


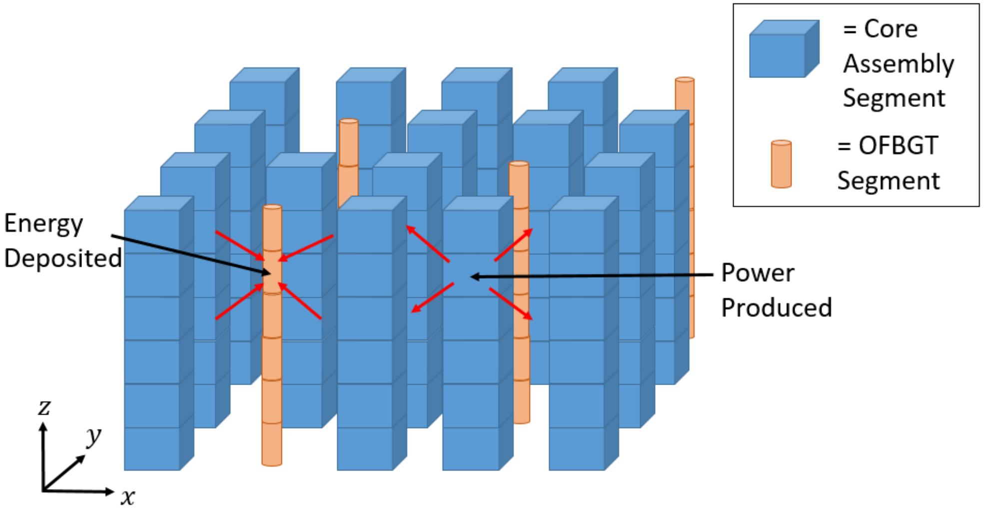
Data Analytic Methodology

- We have developed a 3-step method for inferring the power distribution in a reactor core based on the OFBGT response
  1. Energy Balance Method: utilized to generate response functions so that one may relate energy deposition rate in each OFBGT segment to power produced in each core assembly segment
     - Each OFBGT segment provides an estimate of power in each core assembly segment
  2. Weighting Scheme: The power estimates from each OFBGT segment are weighted in accordance to their energy contribution from each core assembly segment, and then averaged together.
  3. Uncertainty Propagation: Modeling and experimental uncertainty is propagated through Steps 1 and 2

Theoretical Power Profile in 3D Reactor based on OFBGT response



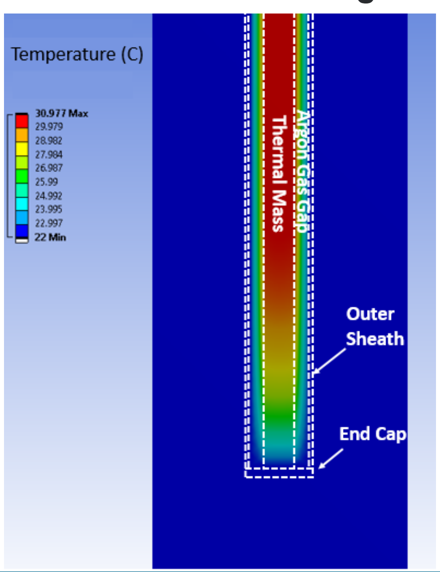




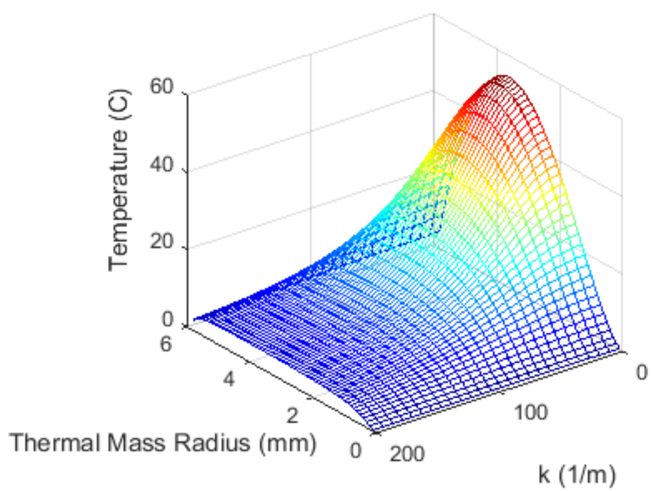
OFBGT Modeling Data

- We have generated both neutronics and thermal performance data regarding the OFBGT performance in OSURR
  - Neutronics data produced with MCNP
  - Thermal performance data produced with ANSYS and a custom analytical model
    - ANSYS allows us to get very detailed information, but is computationally expensive and we can only consider one OFBGT design at a time
    - Custom analytical model provides less detailed information, but is very fast and we can scan the entire OFBGT design space

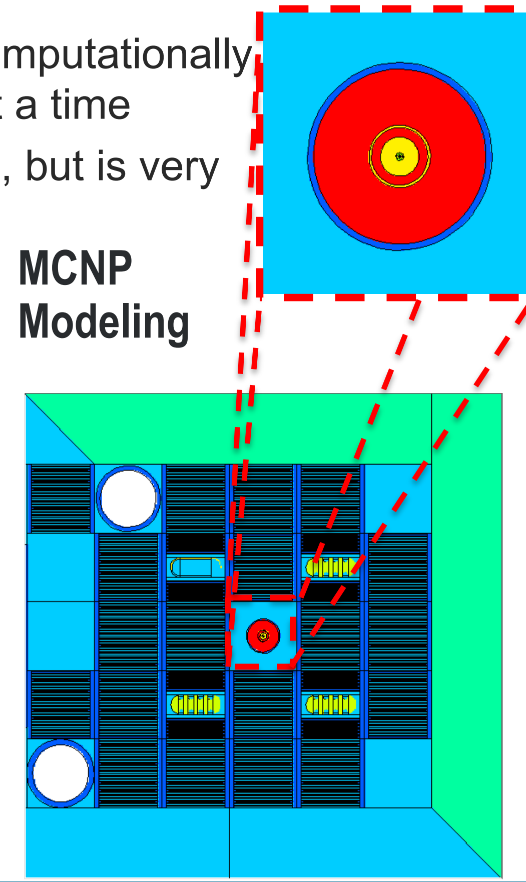
ANSYS Modeling



Sample Space Analysis



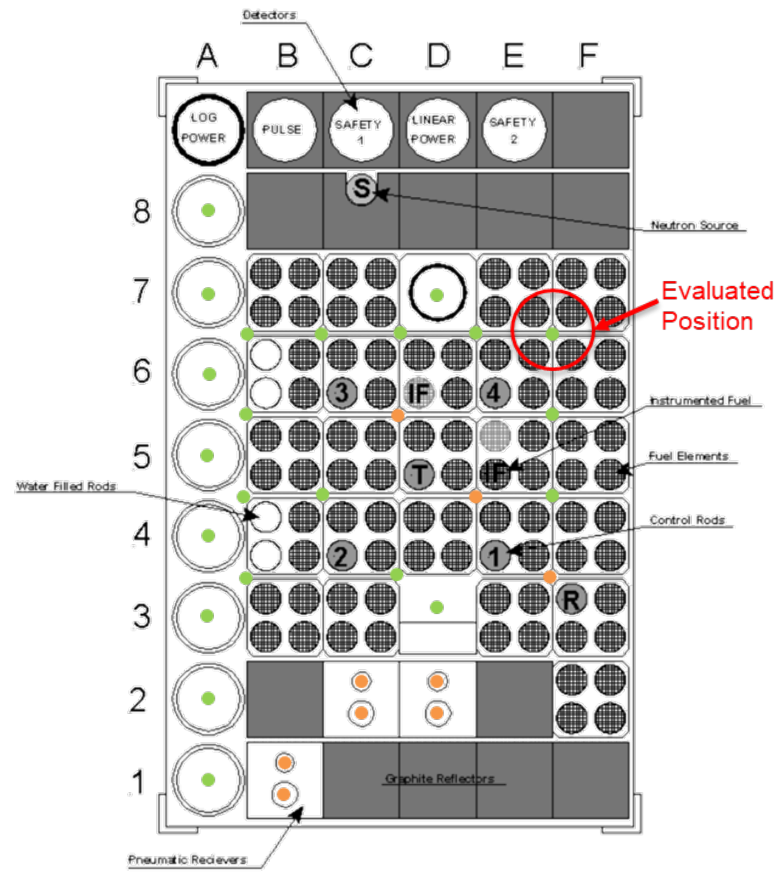
MCNP Modeling



Integration of OFBGT within the TAMU TRIGA

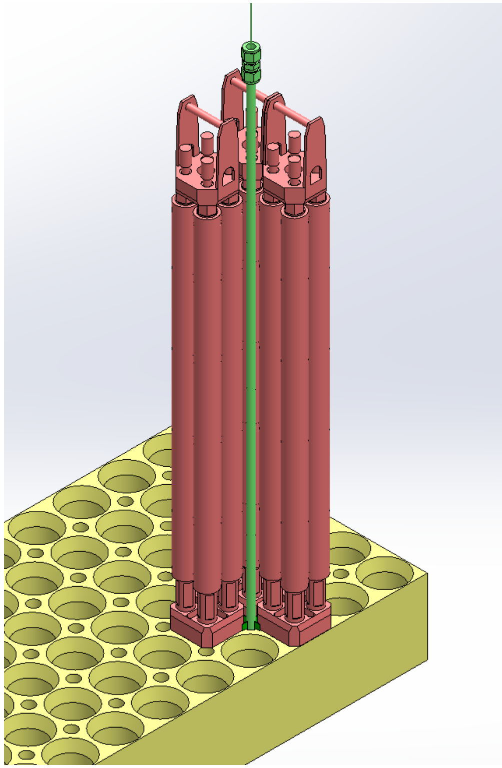
- Supported the OFBGT design and development of the TAMU TRIGA test program
  - Integrated OFBGT design models into the TAMU TRIGA model and assessed performance in in-core environment (MCNP)
  - Satisfies deliverables for Track 1, Task 1.1 and Task 1.2
- Evaluated TAMU TRIGA performance with OFBGTs (MCNP and MatLab)
  - Evaluated multiple sensor locations
  - Developed data analytics methods to assess OFBGTs in TAMU TRIGA
  - Satisfies deliverable for Track 2, Task 1.1.
- Produced simulated data and performed safety evaluations (MCNP)
  - Simulated data for TAMU TRIGA
  - Methods for power reconstruction for TRIGA
  - Satisfies deliverables for Track 2, Task 1.2, and reports on the progress on Task 1.3

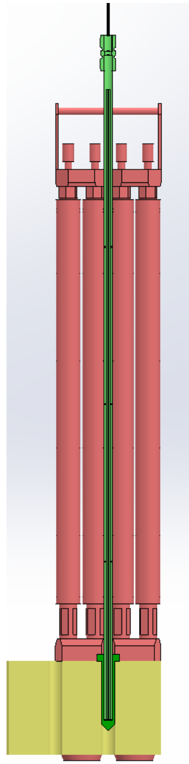
OFBGT Placement within the TAMU TRIGA



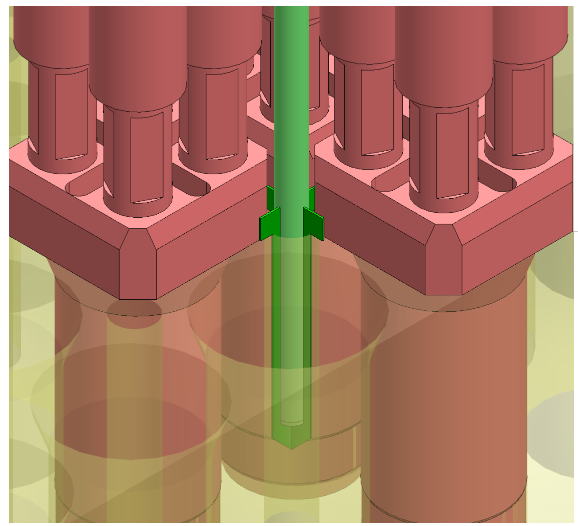
- OFBGT small enough to be placed in corners between fuel assemblies and fit in the cooling channel in the grid plate
- Capability of supporting 8 sensors at a time with interrogation equipment

OFBGT Positioning and Performance Analytics



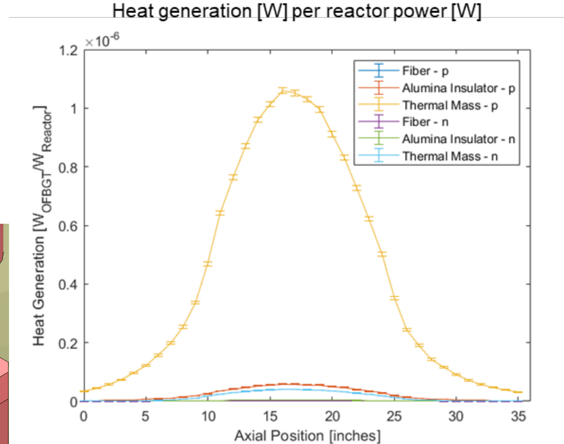


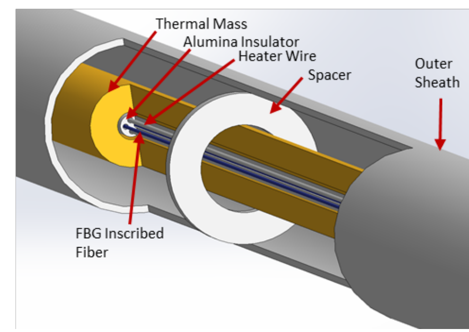
- Shown with OFBGT centered in the fueled region
- Top end fitting several inches above fuel top hats
- OFBGT can be placed without touching fuel assemblies



- At full power (900 kW) the OFBGT produces 14.984 watts of heat
- Not expected to severely limit coolant flow to fuel elements or significantly increase cooling load.
- Reactivity effects most likely due to the reduced coolant in channel, not absorption in the sensor.

Performance Analysis





P = 900 kW	Fiber	Alumina Insulator	Thermal Mass	Total
Photons	2.869 mW	750.769 mW	13.682 W	14.436 W
Neutrons	0.204 mW	49.6012 mW	484.801 mW	534.606 mW
Total	3.072 mW	800.370 mW	14.167 mW	14.970 W

Technology Impact

LPRMs

TIP

OFBGT

- The primary reason for the development of the OFBGT is for the calibration of LPRMs (local power range monitors) in BWRs
  - LPRMs are ion chambers, so they lose sensitivity due to burn-up
  - Currently calibrated with TIPs (traversing in-core probes)
  - TIPs are also ion chambers, so they cannot be permanent fixtures in the core
  - An OFBGT would be a permanent fixture, and could also obtain significantly more data than TIPs (axially distributed sensing)
- OFBGTs could also be used for obtaining core power information in other reactor types
- The OFBGT development answers the demand by the DOE for sensors which support “big data” and data analytics in general
- The OFBGT will be a stand-alone, deployable, and robust system which could be used in the instrument tubes of power reactors

Conclusion

- An OFBGT measures the ΔT along the axial length of the sensor which can be used to infer power distribution using response functions generated by MCNP (ΔT is measured by optical fiber)
- We have completed the design phase of the project and are about to enter the assembly and implementation phase of the silica OFBGT design.
- We have developed the data analytic methods necessary to infer power distribution based on the OFBGT response
- We have generated modeled data which predicts the energy deposition rates in the OFBGT (MCNP) as well as the thermal performance of the OFBGT (ANSYS and analytical modeling)
- Questions?

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