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

Advanced Sensors and Instrumentation

Deployment and In-Reactor Test of an Instrument for Real-Time Monitoring Thermal Conductivity Evolution of Nuclear Fuels

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar
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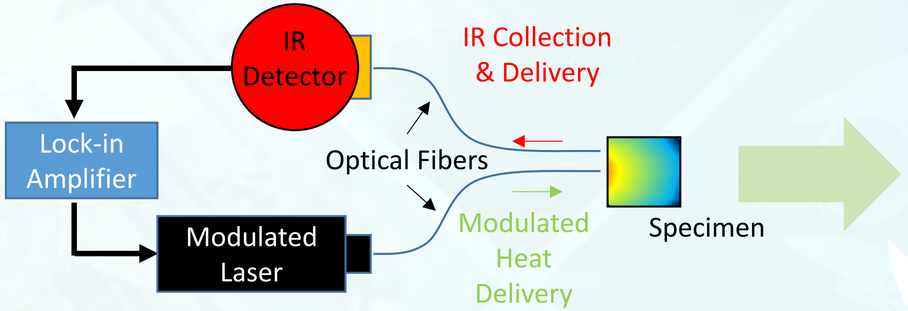
Weiyue Zhou, Michael Short (MIT), David Carpenter (MITR)

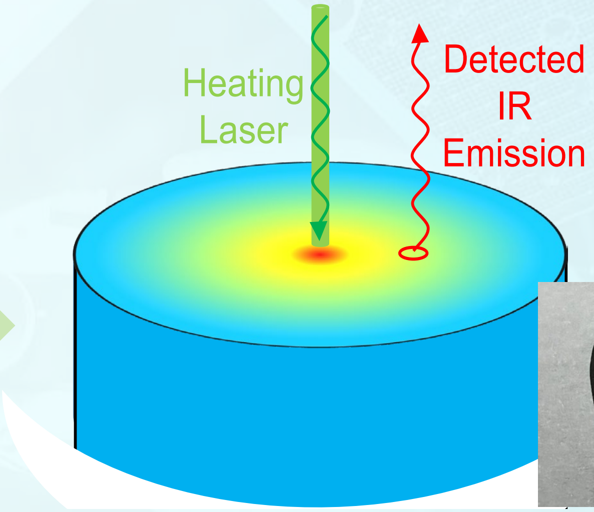
Project Overview

Motivation:

- Thermal conductivity varies significantly in extreme reactor environments
- PIE characterization after reactor shutdown does not capture the defect medicated thermal conductivity under irradiation due to significant defect annealing
- Experimental capability for in situ measurements is currently lacking

In this project, we will deploy and test a photothermal radiometry (PTR) based instrument in MITR. This fiber-based PTR instrument will enable real-time, in-pile thermal conductivity measurements of nucleal fuels and materials.





- No surface preparation
- Ideal for high temperature
- Only require one-side access

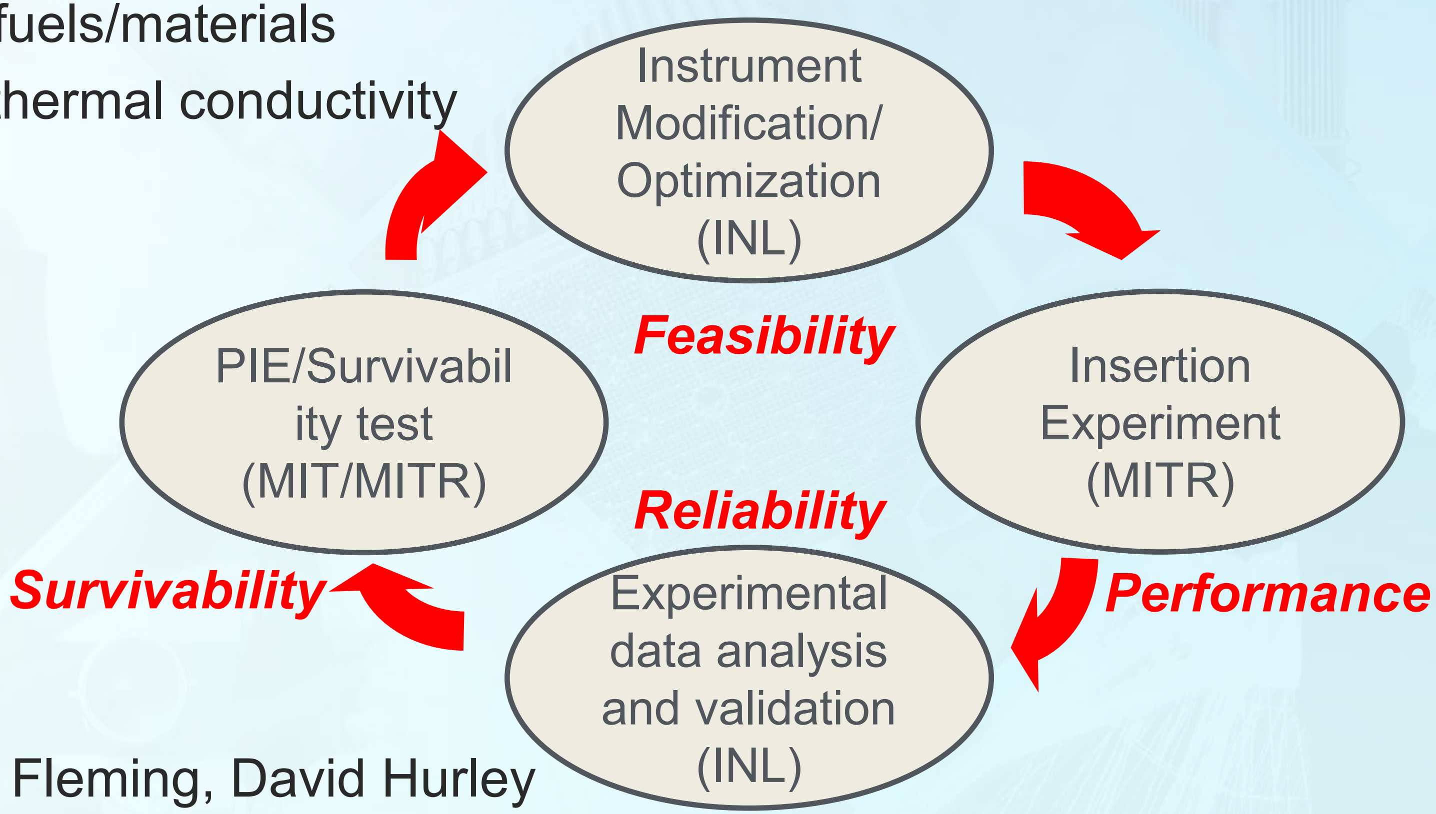
Project Overview

Objectives:

- Test the performance and survivability of the instrument
- Collect real-time experimental data and monitor the thermal conductivity change of reference samples and nuclear fuels/materials
- Develop a user protocol for routine in-pile thermal conductivity measurements

Schedule:

- FY22-25
- Irradiation round #1 (2022/11)
- Irradiation round #2 (2024/01)



Participants:

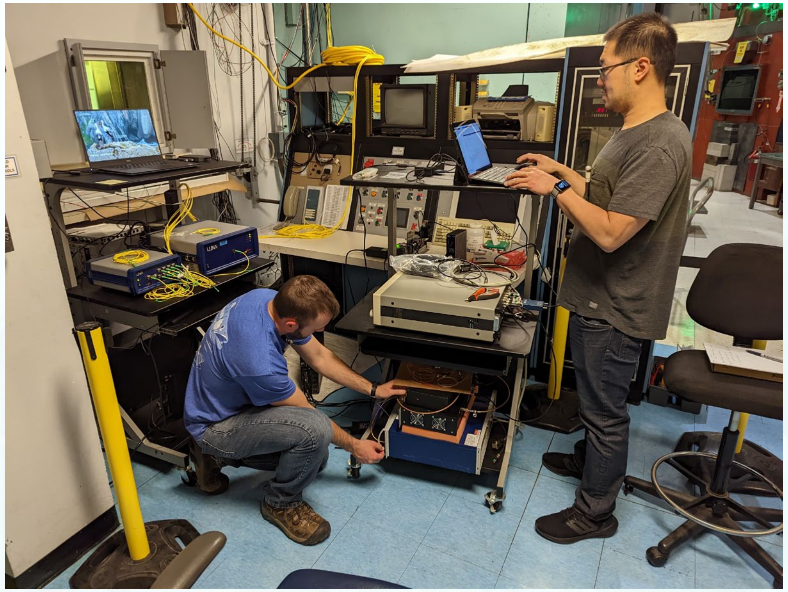
- INL: Zilong Hua, Caleb Picklesimer, Austin Fleming, David Hurley
- MIT: Weiyue Zhou, Michael Short; MITR: David Carpenter

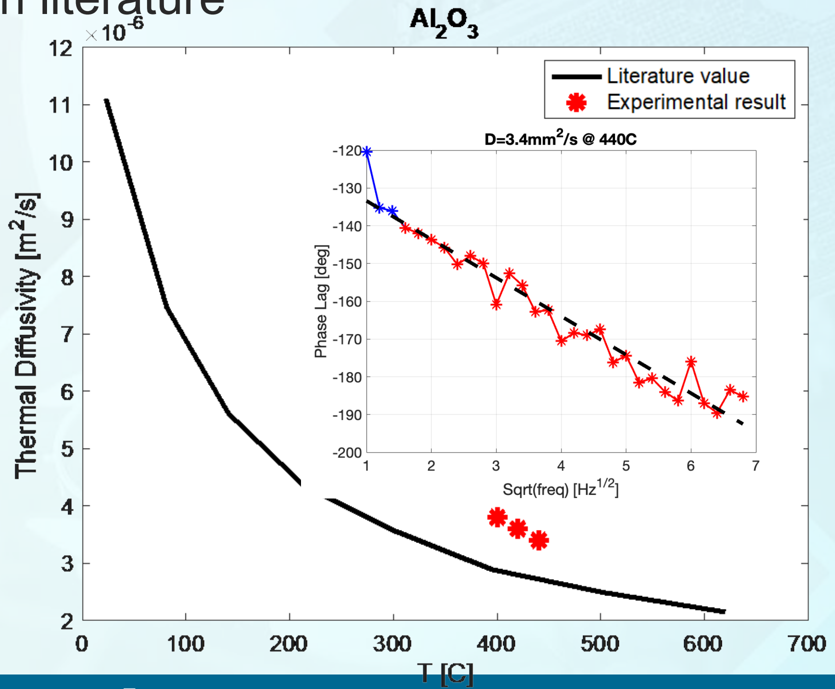
Technology Impact

- The instrument, user protocol and user-friendly interface are expected to make regular in-reactor thermal conductivity measurements of nuclear fuels and related materials feasible
- Real-time, in-reactor thermal conductivity data will
  - Capture dynamic features of microstructure defect generation and evolution
  - Generate tremendous experimental data for computational scientists to validate and verify the advanced fuel performance codes
  - Boost the development of advanced fuels

Results and Accomplishments

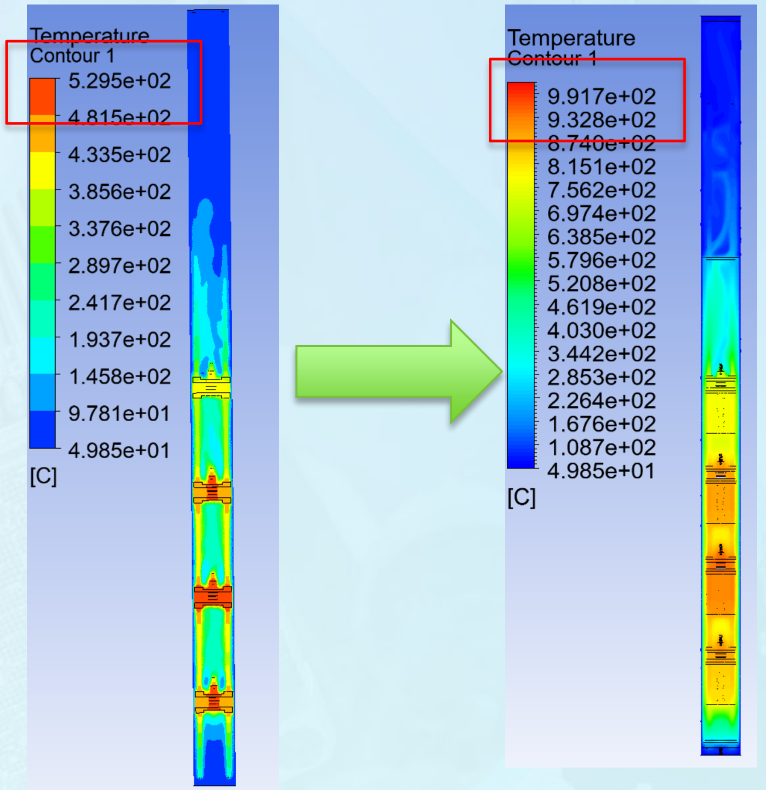
- In-reactor experiment was conducted at MITR
- Thermal diffusivity of Al_2O_3, loaded in probe #2, was collected from reactor in the temperature range of 400-440°C
- A few issues were noticed
  - Probe from other positions and the testing fiber did not return signal
  - Maximum temperature (450°C) was below thermal analysis prediction (530°C)
  - Measured diffusivities are ~25% higher than literature

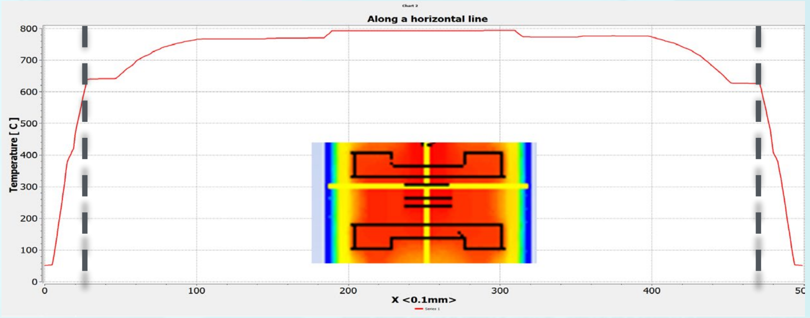




Results and Accomplishments

- Thermal analysis model was updated to
  - Investigate the discrepancy of predicted temperature and measured temperature from reactor
  - Increase the maximum temperature in the in-reactor experiment
- What we did
  - Use the updated heat generation profiles with refined flux and heating rate to improve the simulation precision
  - Use the actual temperature profiles measured from the in-reactor experiment to validate the model
- New design
  - Use a Ti insulation capsule to reduce gas conduction and turbulence convection
  - Use graphite inserts to provide additional heating
- What we get
  - New design will improve the maximum temperature to 950 °C





Results and Accomplishments

- Post-Irradiation-Examination testing was started
  - Optical transmission test on fibers showed that half of the fibers were damaged, likely during insertion and retraction of the instrument
  - Location of fiber damage was identified to be near/in the core position of reactor
  - No blue shift or fiber darkening was noticed
  - Radioactivity of all probes were measured
  - Preloaded samples were removed and transferred to co-investigator's lab, and prepared for thermal diffusivity measurements

Challenges:

- Schedule adjustment
  - MIT research reactor maintenance took longer than expected (8-9 months)
  - PIE testing was delayed with all other projects on the waiting list
  - The second round of irradiation experiment is now scheduled in January 2024

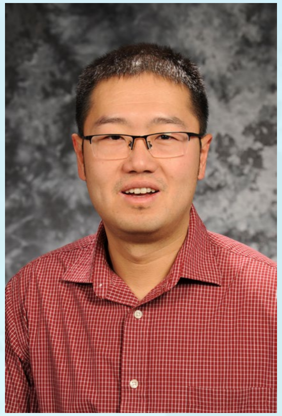
Concluding Remarks

Summary

- Thermal diffusivity data was successfully collected from reactor in the first round of experiment
- Thermal analysis model was improved to provide better simulation precision
- New design of the instrument was expected to increase the maximum temperature from 450°C to 950°C
- PIE testing was started

Future work

- Finalize instrument optimization after PIE testing is complete
- Assemble the instrument for the second round of irradiation experiment (scheduled in 2024/1)
- Latest results will be presented in TMS 2024 and MS&T 2024
- PIE testing after the second round of irradiation experiment; user protocol
- One journal publication is planned



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Thank You