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

Clean. Reliable. Nuclear.

In-core measurement systems for nuclear materials characterization and codes V&V

Advanced Sensors and Instrumentation Annual Webinar

October 29, November 5, November 12 , 2020

Zilong Hua
Idaho National Laboratory

Project Overview

Activity	Objective	Participants in FY20	Schedule
RUSL (Resonant Ultrasonic Spectroscopy – Laser)	Real time monitoring of microstructure evolution, i.e., grain restructuring and phase transformation, of nuclear fuels	Rob Schley David Hurley Zilong Hua Larry Aagesen (INL)	Zero-Group-Velocity plate wave measurements
Needle Probe	Develop and qualify a thermal conductivity measurement technique for prototypic in-pile conditions	Austin Fleming Kurt Davis (INL) Katelyn Wada David Estrada (BSU)	
EIS (Electrochemistry Impedance Spectroscopy)	Develop EIS-based sensor for in-situ measurement of cladding corrosion	Hongqiang Hu Ling Ding (INL) Mike Hurley Claire Xiong Min Long Michael Reynolds (BSU)	
PTR (Photothermal Radiometry)	Contactless, remote thermal conductivity measurement	Zilong Hua Rob Schley David Hurley (INL)	In-situ/in-core experiments

Summary of accomplishments

- Milestones:
  - RUSL
    - Complete design of RUSL irradiation experiment with free standing sample
    - Define specifications for RUSL Validation and Verification test for fuel microstructure characterization in coordination with NEAMS
    - Scoping studies to ascertain the change in the phase transition temperature of metallic fuels
  - EIS
    - Test the Electrochemical Impedance Sensor (EIS) sensor at PWR relevant conditions in static autoclave and perform finite element (FE) models
    - Study of corrosion of cladding material in simulated PWR environment using impedance measurement
  - Needle Probe
    - Development and out-of-pile testing of a novel line source method for measuring nuclear fuels and materials
  - PTR
    - Demonstration of bench-top fiber-based Photo Thermal Radiometry (PTR) system to measure nuclear fuels and materials thermal conductivity
    - Complete feasibility assessment for the applicability of PTR to irradiation experiments

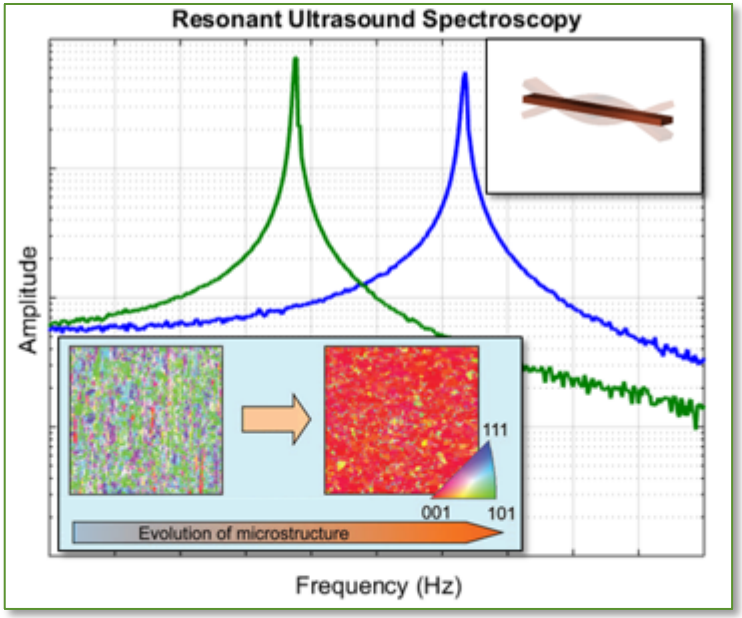
Technology Impact

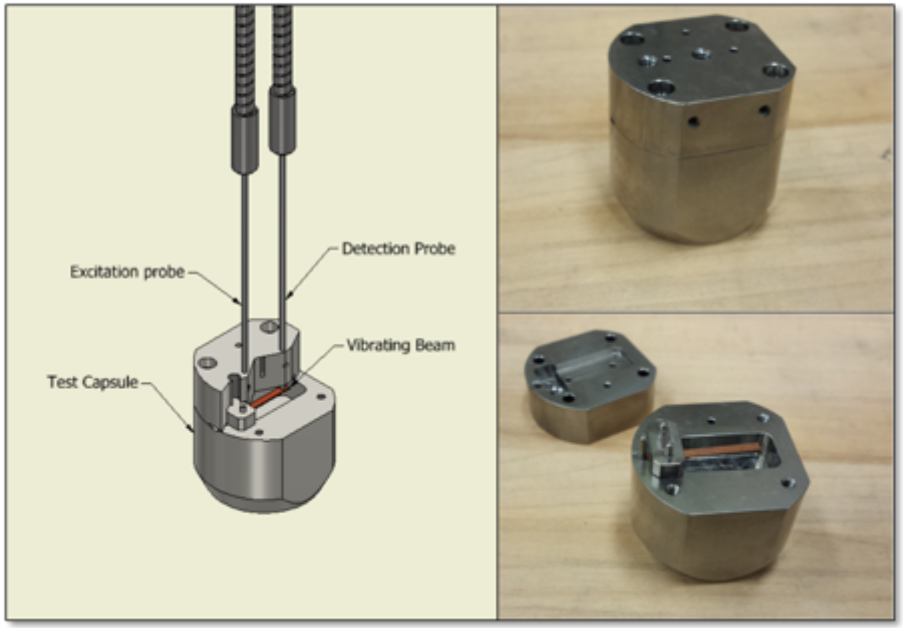
In-core measurement systems

- Monitor the critical physical property or important phenomena relating to nuclear reactor safety and efficiency
  - Thermal conductivity
  - Microstructure evolution
  - Cracking
  - Corrosion
- Provide real-time information in coupled extreme environments, which is lacking from PIE
- High TRL for commercialization

Accomplishments (1/4 - RUSL)

- Elasticity properties – microstructure evolution
- Previous cantilever beam capsule
  - In-core test performed at TREAT, with good results obtained

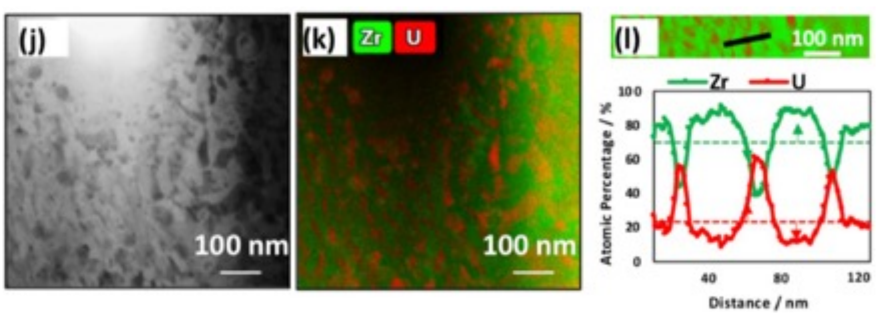


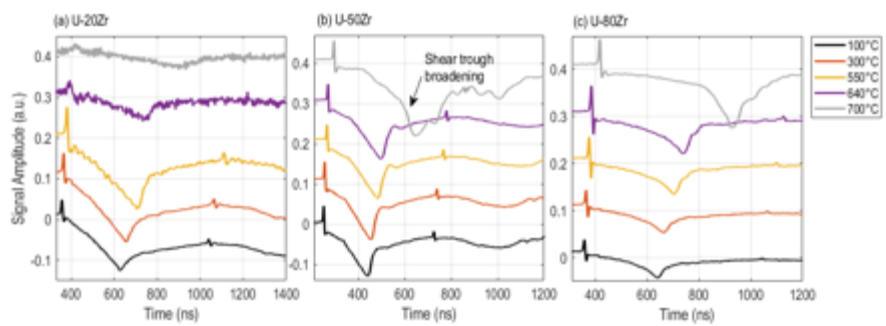


MIMIC-RUSL Test Capsule

Accomplishments (1/4 - RUSL)

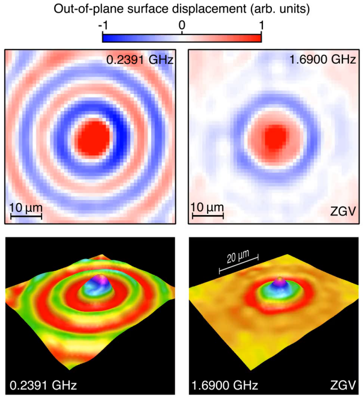
- External Funding resulting from FY19 work
  - NNSA funding for the aLEU-RUSL which will implement this measurement technique for the study of phase transition temperatures of Low Enriched Uranium (LEU) U-Mo
  - A sister experimental-computational study on U-Zr: irradiation induced phase transformation





Accomplishments (1/4 - RUSL)

- Novel zero group velocity (ZGV) plate wave measurements
  - Remove ultrasonic attenuation from coupling with environments
  - Have low losses and high Q-factor
  - Measure intrinsic attenuation related to dislocation density

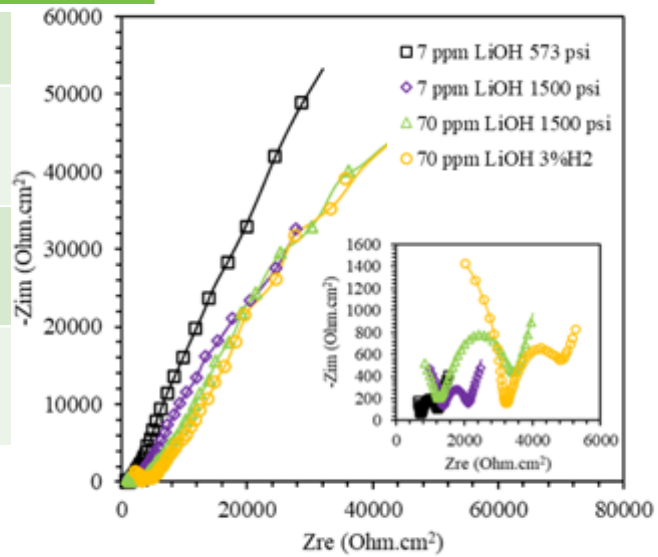


Q. Xie et al., "Imaging gigahertz zero-group-velocity lamb waves," Nature Communication, 10, 2228 (2019)

Accomplishments (2/4 - EIS)

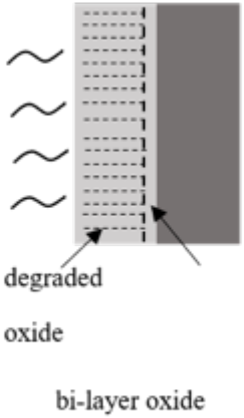
- In-situ EIS experiment
- Results compared favorably with industry standard method

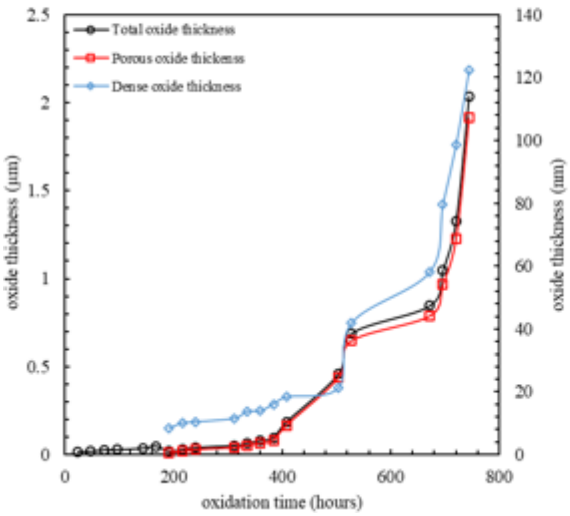
Testing conditions	Oxide thickness calculated from weight gain (µm)	Oxide thickness calculated form cole-cole diagram (µm)
Water	0.44	0.312
7 ppm LiOH/573 psi	1.06	0.315
7 ppm LiOH/1500 psi	1.51	1.30
70 ppm LiOH/1500 psi	2.66	1.89

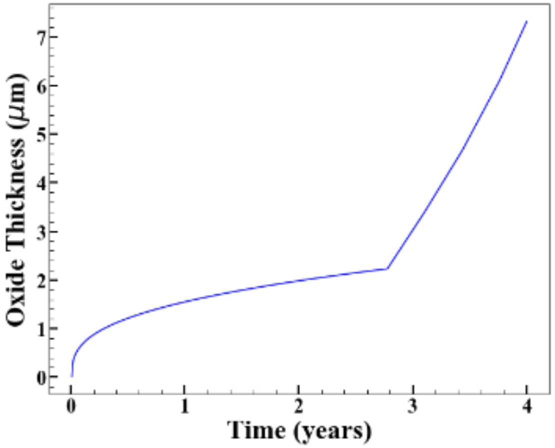


Accomplishments (2/4 - EIS)

- Real-time oxide development recorded
- Threshold safety parameter proposed (represented by impedance)
  - Oxide thickness
  - Corrosion rate
- FEA Modeling
  - 7.2 µm of oxide after 4 years
  - Maximum depth of hydride penetration will not happen at surface

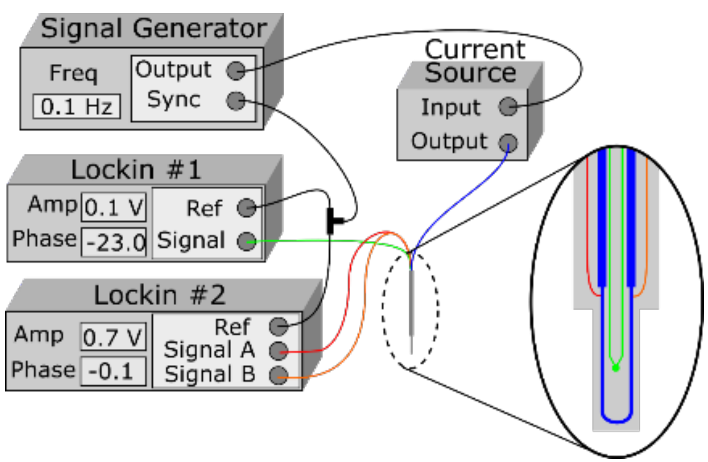


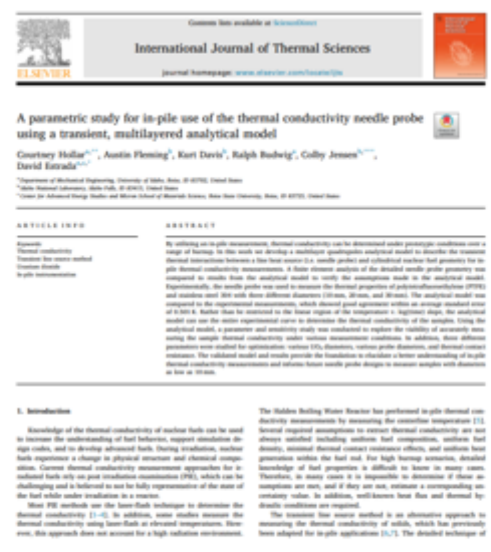




Accomplishments (3/4 – Needle probe)

- Building on previous work with in-pile line source methods to improve high temperature performance and smaller sample size.
- FY20 work focused on establishing a new measurement technique which would eliminate the need for a thermocouple, thereby minimizing the probe size and cross talk problems at high temperatures.




Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

A parametric study for in-pile use of the thermal conductivity needle probe using a transient, multilayered analytical model

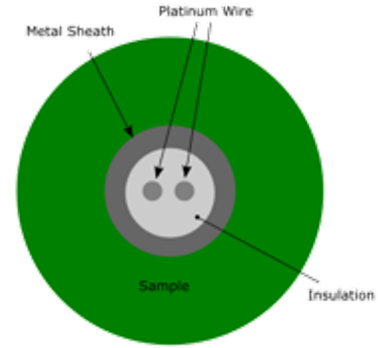
Courtney Hollar, Austin Fleming, Kurt Davis, Ralph Budwig, Colby Jensen, David Estrada

ARTICLE INFO

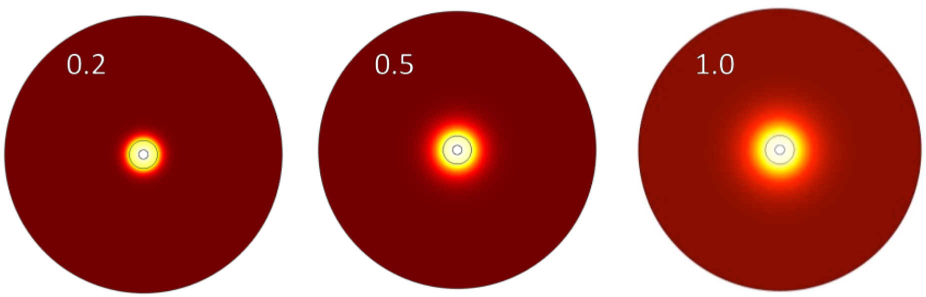
ABSTRACT

Accomplishments (3/4 – Needle probe)

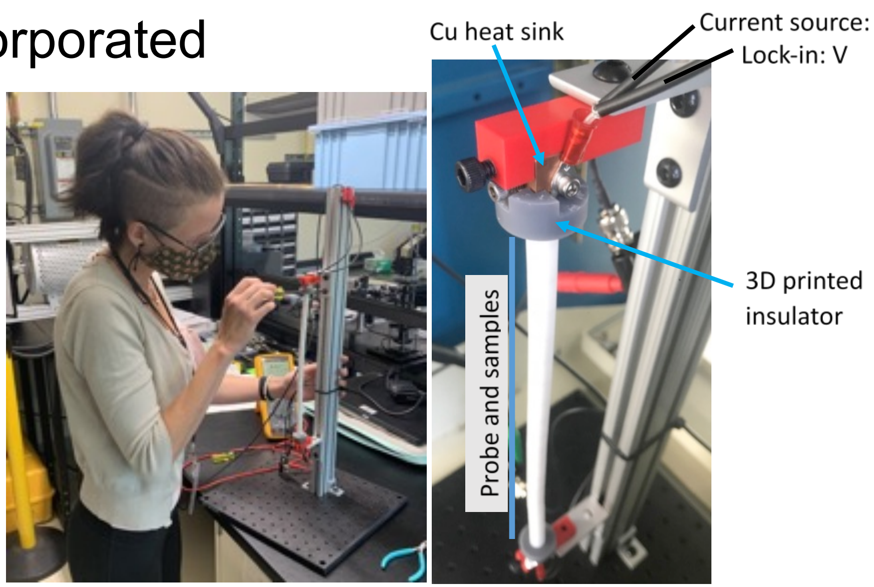
- Theoretical foundations were established for a “hybrid” technique between the 3-omega and transient line source techniques
- A probe compatible with this technique was designed and procured
- Analytic and FEA (COMSOL) models were developed for this new probe geometry
- Test samples were procured and incorporated into a test stand at INL



Cross-section of new probe geometry being tested



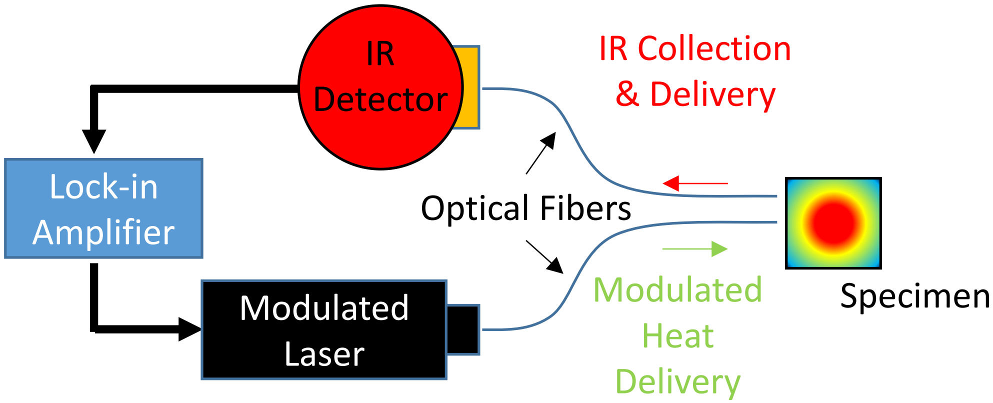
COMSOL modeling results of the new probe geometry at three different time

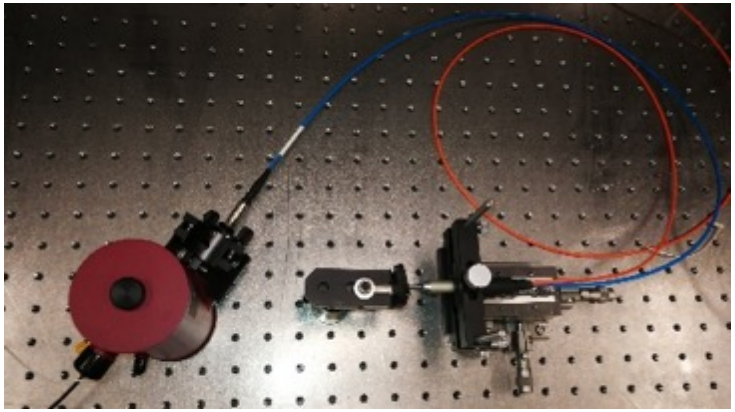


Katelyn Wada (Intern from Boise State University) experimentally tests the novel needle probe

Accomplishments (4/4 - PTR)

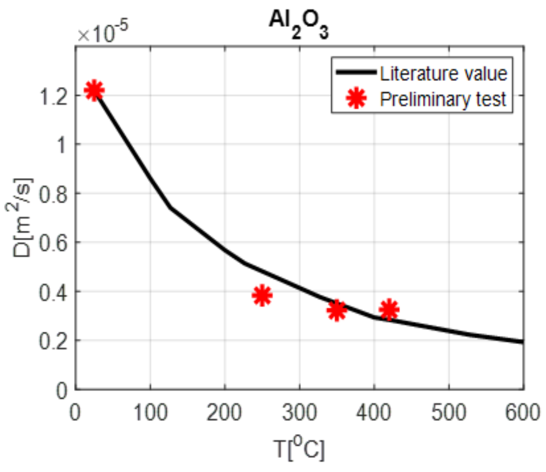
- Thermal wave – thermal conductivity
- Blackbody radiation – unique advantages
- Free-space system validated on a set of reference samples; new measurement methodology developed

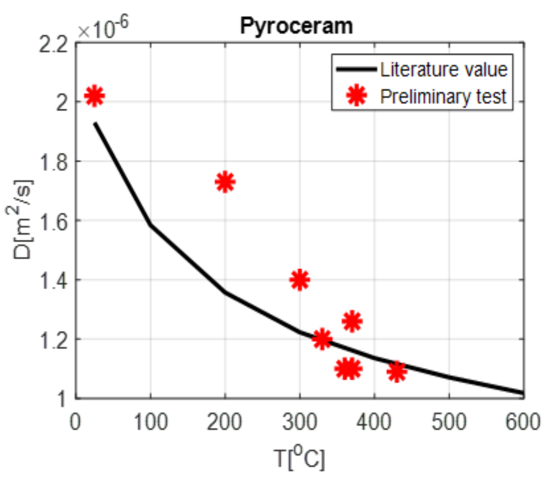


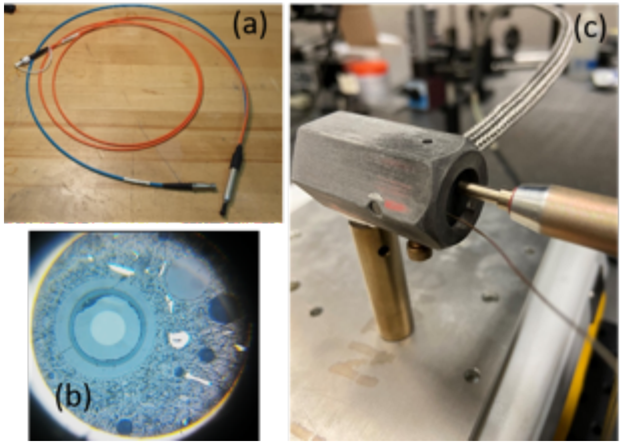


Accomplishments (4/4 - PTR)

- In-core instrument designed, fabricated, and tested
  - First generation (room temperature)
  - Second generation (200-700C; test up to 500C)







Conclusions/Look ahead

- In-situ PTR tests performed with promising results obtained
- In-core tests performed or scheduled
- Journal papers (PTR) prepared

Zilong.hua@inl.gov

Tel: 208-526-0644/Cell: 435-764-6725