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

Clean. Reliable. Nuclear.

Overview of NEET ASI Direct Funded Projects

Advanced Sensors and Instrumentation Annual Webinar

October 30, 2019

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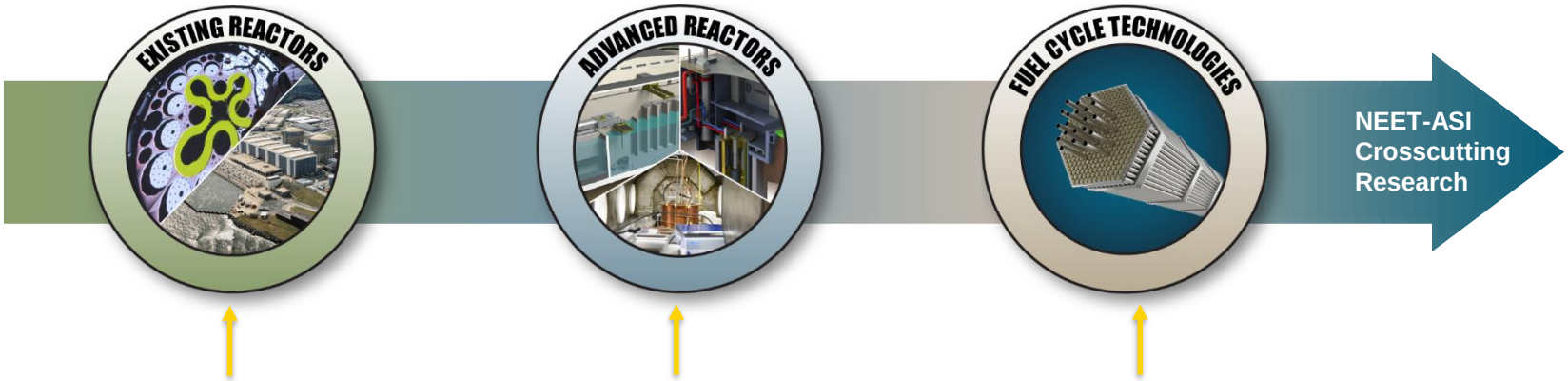
Idaho National Laboratory

Project Overview



Direct funded activities for demonstration in plant conditions: test sensor technologies today in MTRs irradiation experiments to mature technologies in support of three main NE mission

Close technology lifecycle / pursue early adoption strategies

NE programs

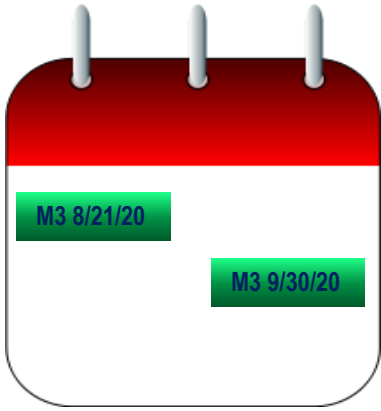
Nuclear vendors
I&C suppliers

Project Overview

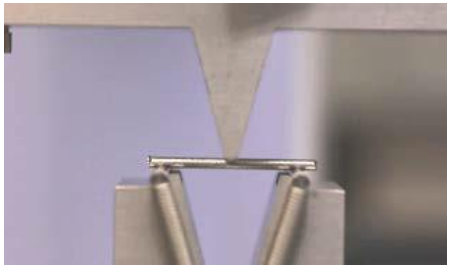
Nuclear instrumentation	Instruments to measure process parameters (temperature, pressure, …)
Advanced manufacturing	Advanced Manufacturing Techniques for Sensors Fabrication
Material properties	Measurement systems for nuclear materials properties characterization
Instrumentation deployment	Technology demonstration in conditions relevant to nuclear power system

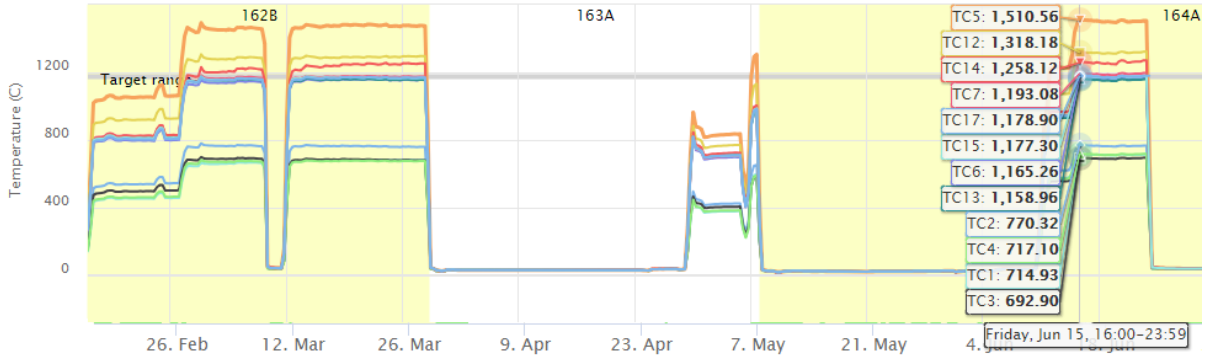
Thermocouples (baseline capability)*

- FY20 activities – High Temperature Irradiation Resistant thermocouple (Mo-Nb junction):
  - Long term drift assessment of optimized HTIR design (Coaxial)
  - Test HTIR in ATR conditions (assembled rig in flowing autoclave)
    - Molybdenum sheath vs. Niobium Sheath
  - Modeling of thermocouple elements response
    - first principle, combinatorial MS (↔ AM)



- FY19 accomplishments
  - Solved issues with mechanical reliability of HTIR Nb sheath
  - Demonstrated HTIR performance under irradiation (AGR5/6/7)





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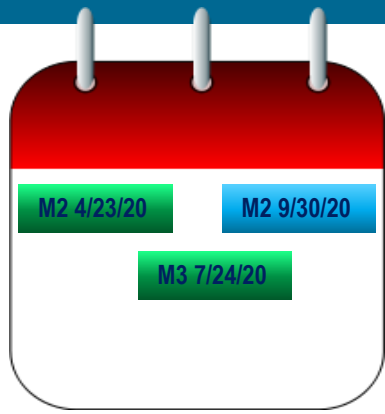
Neutron flux sensors (baseline capability, innovative sensors)

- FY20 activities:
  - Develop SPNDs for steady-state reactor operation
  - Finalize fission chamber calibration procedure
  - Develop strategies for radiation tolerant electronics



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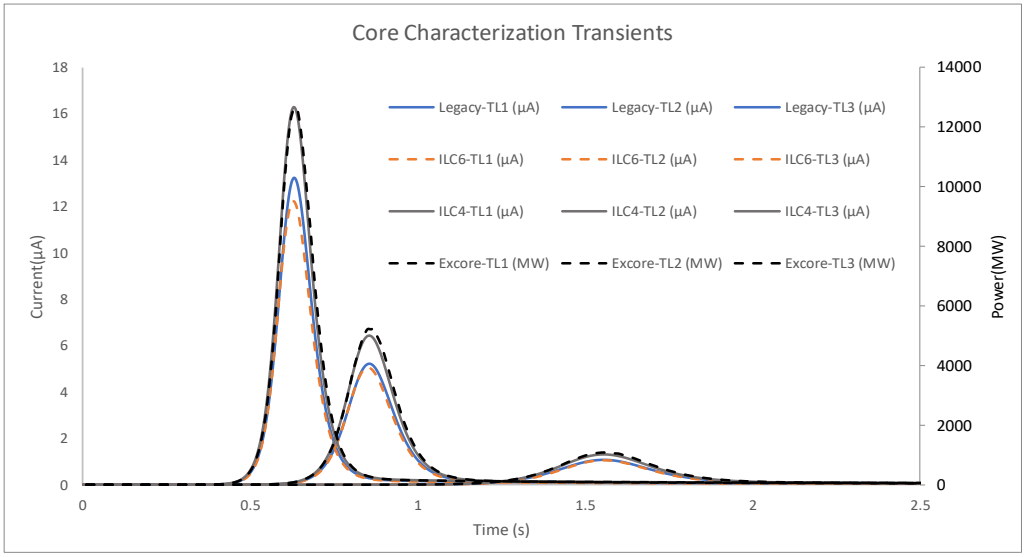
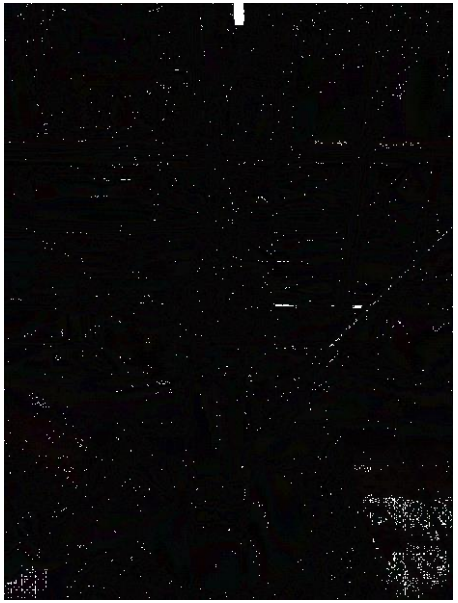
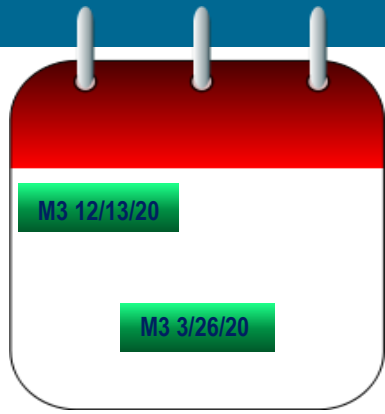
- FY19 accomplishments
  - Demonstrated capability to design/fabricate custom SPNDs at INL
  - Demonstrated performance of Ga-SPNDs for transient test (TREAT)





Passive sensors (baseline capability, innovative sensors)

- FY20 activities:
  - SiC monitors for average irradiation temperature
    - Assessment of pre-annealing processes
  - Develop melt wire arrays fabricated by advanced manufacturing



- FY19 accomplishments
  - Demonstrated automated post-processing of irradiated SiC rods
  - Developed neutron dosimeters for in-pile applications fabricated by additive manufacturing

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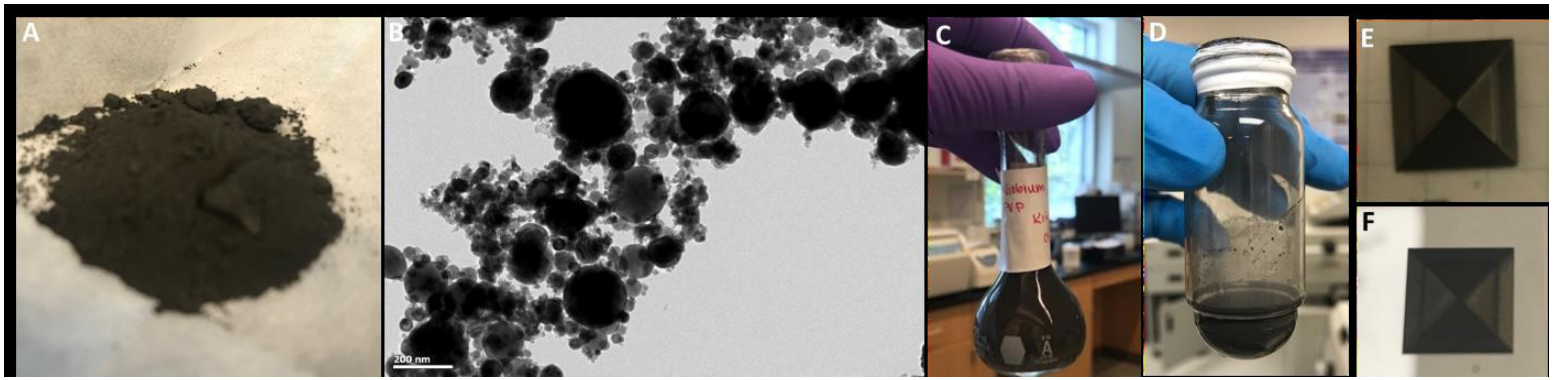

Process for the fabrication of Niobium dosimeters (1x1 cm for demonstration)

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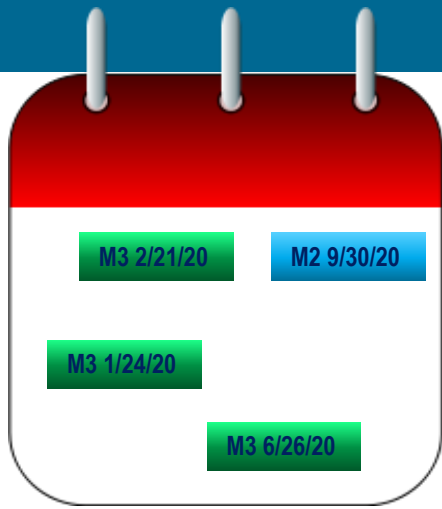
Acoustic sensors (innovative sensors)

- FY20 activities:
  - Demonstrate operating window of Ultrasound Thermometer with reference transducer/waveguide design (temperature, pressure)
  - Acoustic (Surface Acoustic Wave) sensor fabricated by advanced manufacturing techniques
  - Optically coupled ultrasonic thermometer
- FY19 accomplishments
  - Matured reference UT design for distributed temperature measurement (DISECT experiment)
    - Transducer and waveguide are separate parts
    - Stainless steel waveguide with good sensitivity to 1000 C
    - MITR (ULTRA) and ATR (AGR5/6/7) results



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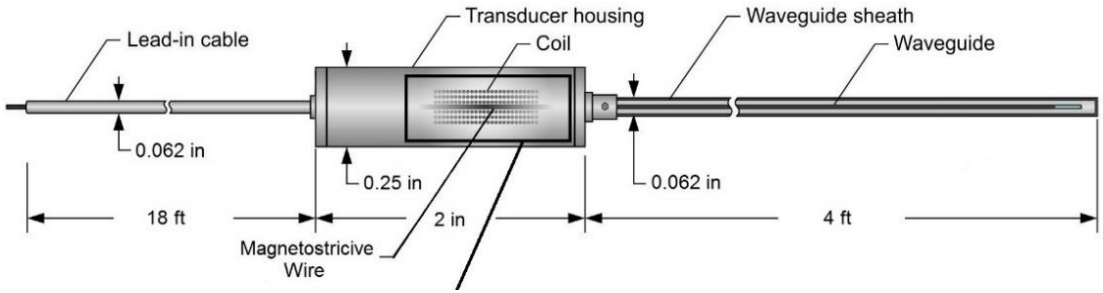
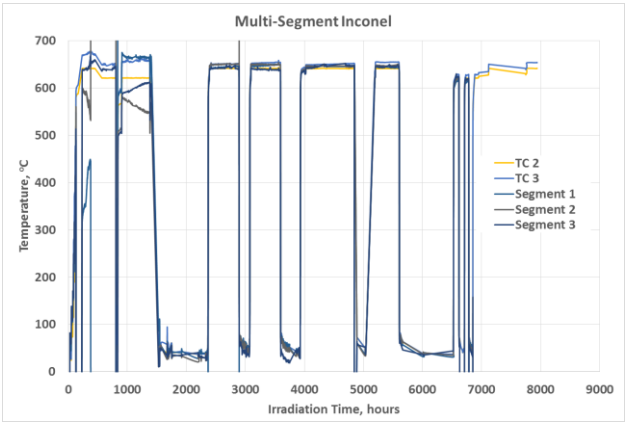
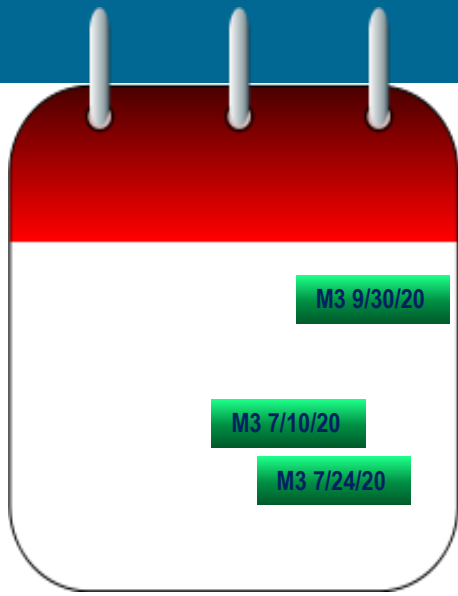
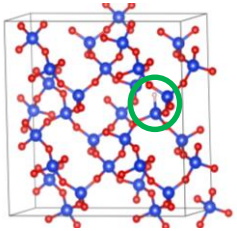




Fiber optic sensors (innovative sensors)

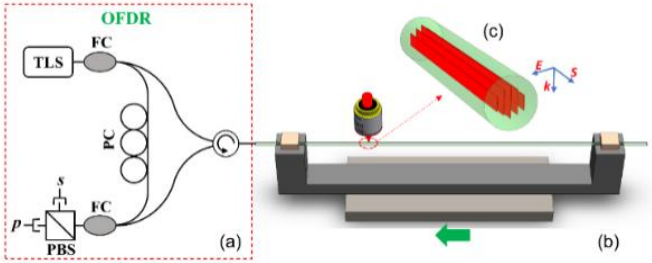
- FY20 activities:
  - Intrinsic Temperature Sensors (FBG/DTS)
    - Develop active compensation techniques for OF sensors operating in radiation environments
  - Develop Pressure Sensor based on Fabry-Perot interferometry
  - Develop pressure feed through for OF
  - Assess in-pile imaging with OF bundles
- FY19 accomplishments
  - Characterized the limits of radiation induced degradation on specialized fiber materials (Pure Si core/F-doped clad, RAL), advanced fabrication (type II FBGs) and interrogation (Optical Frequency Domain Reflectometry, tunable laser) tecniques





Modeling oxygen deficient centers (ODCs) and the effect of H dopant on refractive index

Type II FBGs fabricated by fs laser:
- Direct writing – point-by-point
- Phase mask



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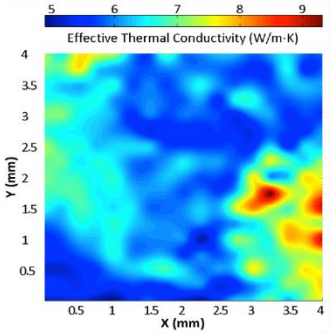
Wireless communication (innovative sensors)

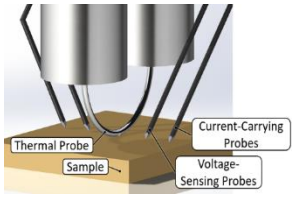
- FY20 activities:
  - Assessment of Wireless communication technologies and their application in nuclear environment to support development of a technology demonstration test plan

Advanced manufacturing (innovative sensors)*

- FY20 activities:
  - Process control for sensor fabrication
    - Refine printing processing parameters for sensors fabrication: melt wire arrays, Ultrasound Thermometers, thermocouples
  - Feedstock (ink) development
    - Develop and characterize nanoparticle based inks for sensors fabrication (Thermocouples, piezoelectrics)
  - Combinatorial Material Science
    - Rapid screening of sensors materials
- FY19 accomplishments
  - Fabricated dosimeters and strain gauges using AJP
  - Developed Mo, Nb, Pt, Fe, Co, Zn, W and In inks
  - Performed study on irradiated combinatorial film ($ZnSnN_2$)



Thermal conductivity analysis of TiNiSn sample



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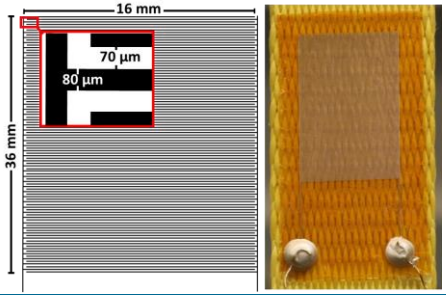
Printed strain gauge (Silver on Kapton with Kevlar strap)

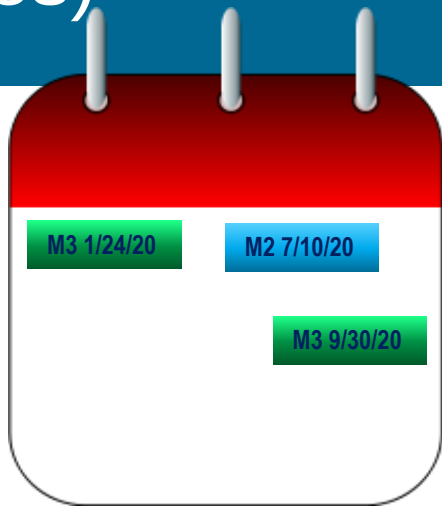


Material	Commercially Available?	Target Printer	Sensor
Zinc	N	AJP/PJP	Dosimeter, Melt Wires
Indium	N	AJP/PJP	Dosimeter, Melt Wires
Maganese	N	AJP/PJP	Dosimeter, Melt Wires
Gold	Y	AJP/PJP	Dosimeter, Melt Wires
Sodium	N	AJP/PJP	Dosimeter, Melt Wires
Magnesium	N	AJP/PJP	Dosimeter, Melt Wires
Aluminum	N	AJP/PJP	Dosimeter, Melt Wires
Scandium	N	AJP/PJP	Dosimeter, Melt Wires
Gallium	N	AJP/PJP	
Rubidium	N	AJP/PJP	
Yttrium	N	AJP/PJP	
Zirconium	N	AJP/PJP	
Ruthenium	N	AJP/PJP	
Tantalum	N	AJP/PJP	

AM dosimeters

Mechanical properties (material properties)

- FY20 activities:
  - Assess performance of LVDT-based creep test rig
  - Develop methods for strain and radial deformation (diameter gauge) measurement in irradiation experiments
  - Support LVDTs deployment in irradiation experiments
- FY19 accomplishments
  - Design and constructed a mechatronic-based test bed for strain, deformation and vibration sensors characterization
  - Design and constructed LVDT-based creep test rig
  - Design and constructed LVDT-based pressure measurement system for fission gas release inside fuel pins



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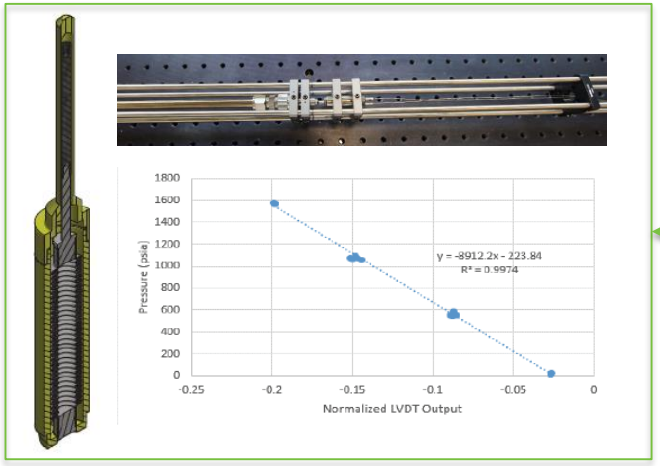
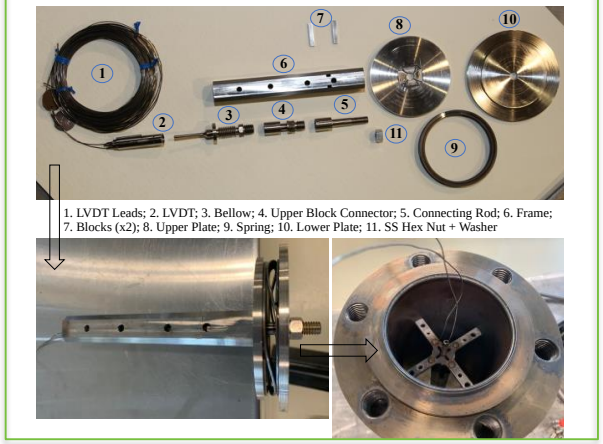
University of Pittsburgh

Creep measurement rig

Halden capabilities recovery





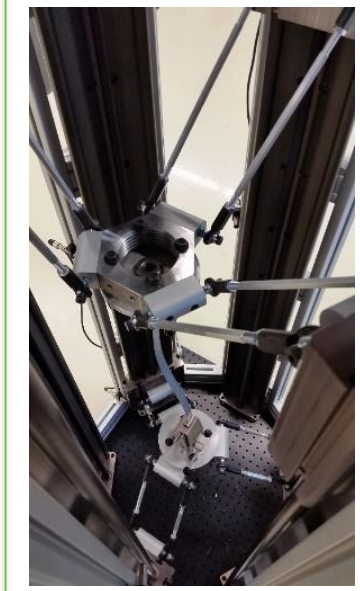
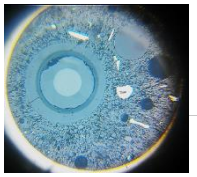
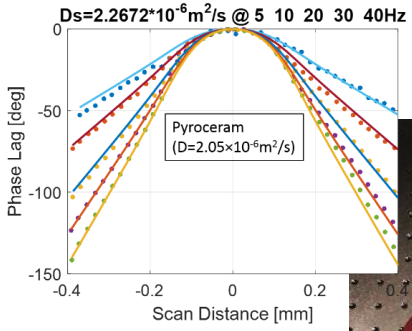


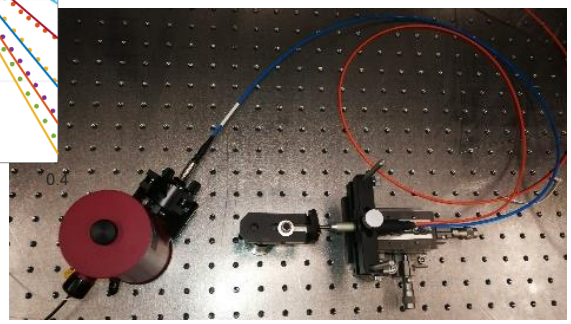
Photo-thermal radiometry (material properties)

- FY20 activities:
  - Demonstration of bench-top fiber-based Photo Thermal Radiometry (PTR) system to measure nuclear fuels and materials thermal conductivity
    - Develop ZEMAX-based model of detection for optical transfer function
  - Initiate the adaptation of benchtop system to the irradiation test capsule for TREAT
- FY19 accomplishments
  - Demonstrated feasibility of using PTR in irradiation experiments



Fiber-optic based in-pile system





Benchtop setup and preliminary results

Probe method (material properties)*

- FY20 activities:
  - Perform out-of-pile testing of innovative line source probes to measure nuclear fuels and materials thermal conductivity in irradiation experiments
    - Demonstrate applicability of frequency response method

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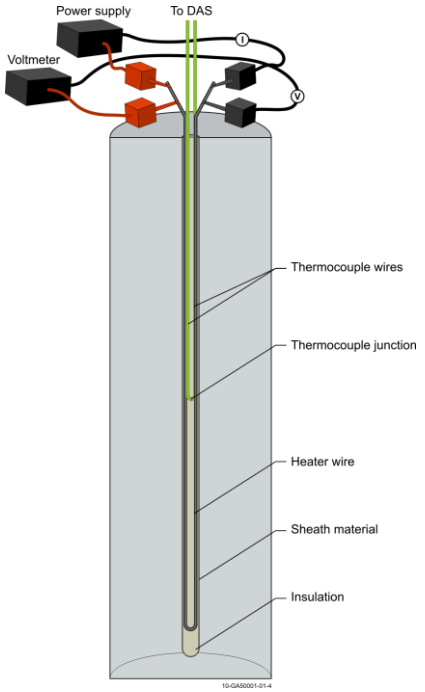
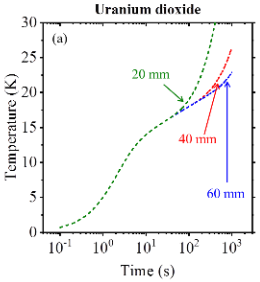
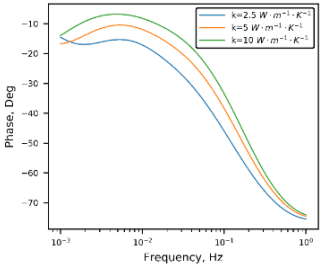
- FY19 accomplishments
  - Extended applicability of INL/USU patented probe design through advanced analytic techniques and design optimization
    - Accounted for the effect of contact resistance and finite specimen size



Time Domain



Frequency Domain



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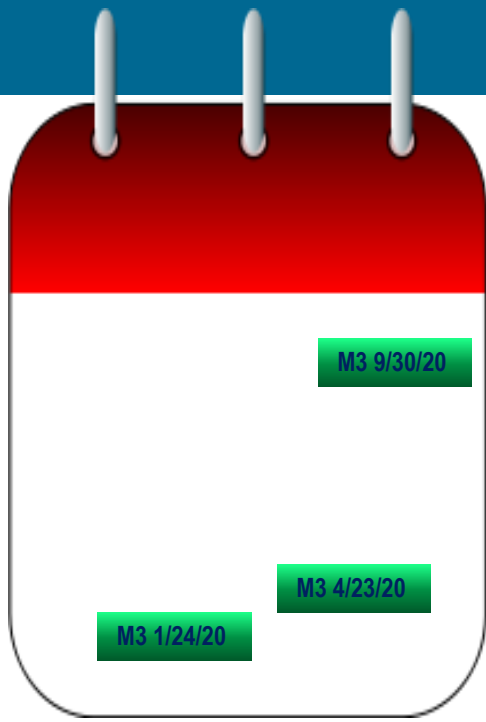
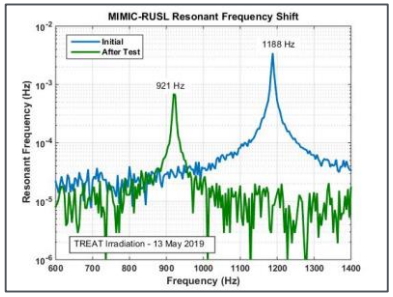
Resonant Ultrasound Spectroscopy (material properties)*

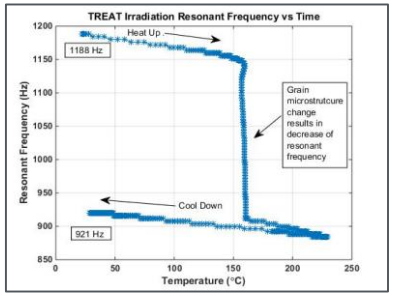
- FY20 activities:
  - Modify RUSL capsule design
    - Free-standing samples (vs current cantilever beam mode)
    - Enable interferometric detection (vs current knife edge mode)
  - Identify base material, starting microstructure, and irradiation conditions that will demonstrate the influence of irradiation on microstructure evolution
    - Coordinate with NEAMS for fuel microstructure models V&V
    - Identify change in the phase transition temperature of metallic fuels
- FY19 accomplishments
  - Demonstrated feasibility of in-pile monitoring of the microstructure evolution of nuclear fuel
    - TREAT test performed using an optical fiber based technique that measured the elastic properties of a small cantilever beam (Cu)



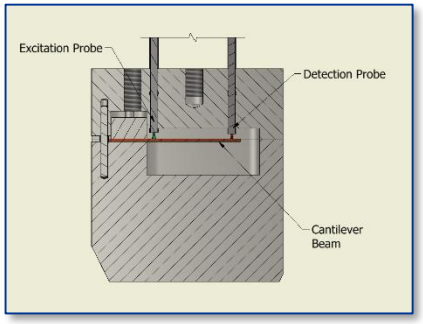
The excitation probe delivers chopped laser heating to the base of the cantilever beam to excite vibration.

The detection probe is positioned at the tip of the beam for maximum sensitivity.

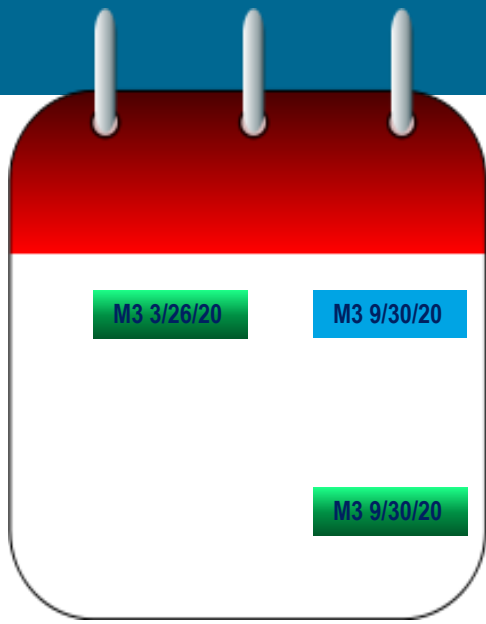




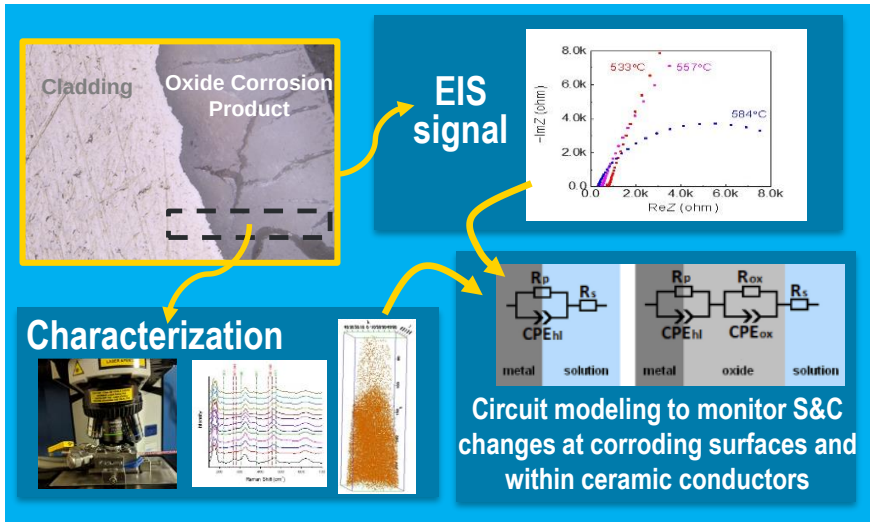
1rst flexural mode resonance shift due to recrystallization



Electrochemical measurements (material properties)



- FY20 activities:
  - Characterize Electrochemical Impedance Sensor (EIS) performance in prototypical (PWR) conditions
    - Design/assess sensor for water chemistry characterization in irradiation loops
  - Develop modeling and simulation tools to correlate EIS results with the structure evolution of hydrides and oxides in nuclear cladding materials
- FY19 accomplishments:
  - Demonstrated feasibility of space and time resolved monitoring of cladding chemical changes using EIS
    - EIS data has been preliminarily correlated to oxide/hydride structure in controlled laboratory conditions
  - Developed prototype EIS sensor for further testing of chemistry and structure



C.M. Efaw, J.L Vandegrift, M. Reynolds, S. McMurdie, B.J. Jaques, H. Hu, H. Xiong, M.F. Hurley, "Characterization of Zirconium Oxides Part I: Raman Mapping and Spectral Feature Analysis," J. Nuclear Materials & Energy, August 2019

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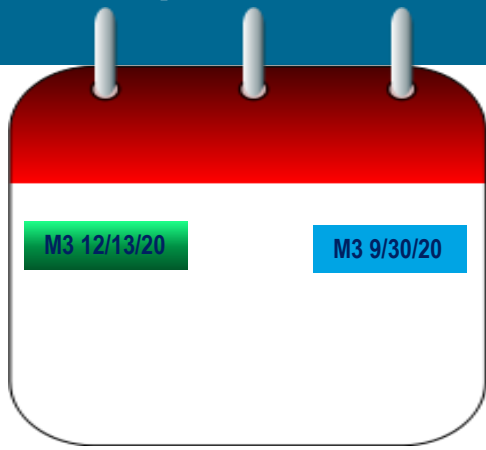
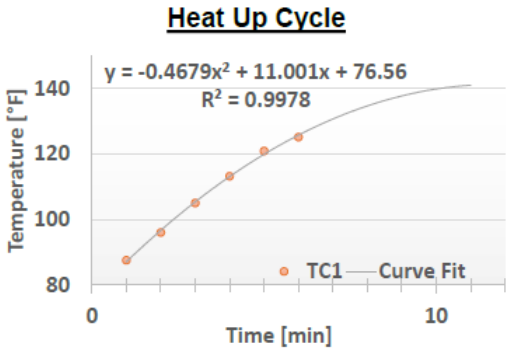
Autoclave test (Instrumentation deployment)

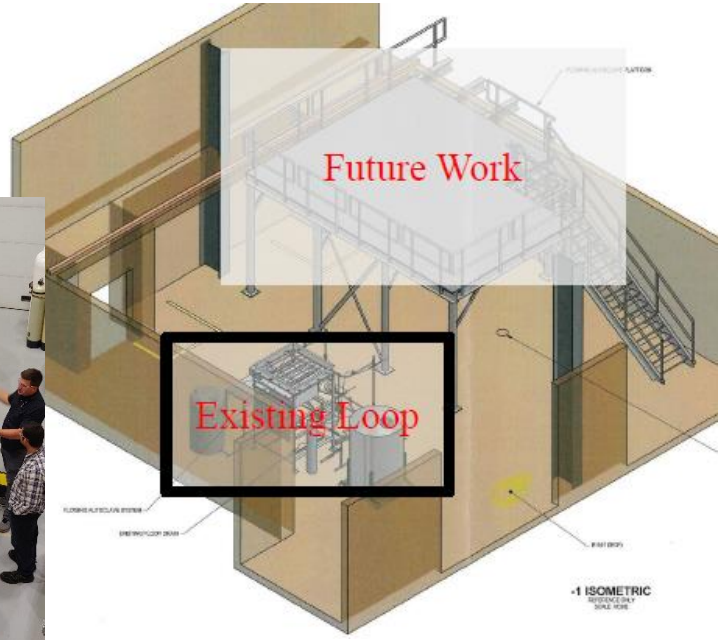
- FY20 activities:
  - Upgrade water loop for testing in PWR conditions to accommodate test sections with relevant ATR geometry
  - Operate flowing autoclave to assess instrumentation reliability
    - Research plan priorities: HTIRs, LVDT, creep test rig



- FY19 accomplishments:
  - Flowing autoclave commissioning test performed on schedule 9/4/2019

Halden capabilities recovery





Fuel re-fabrication facility (Instrumentation deployment)

- FY20 activities:
  - Provide design support, procure from Halden and assembly the prototype unit of the INL fuel re-fabrication facility
  - Design and fabricate under water high pressure feedthrough based on Halden design
    - First deployment in ATR-C irradiation test

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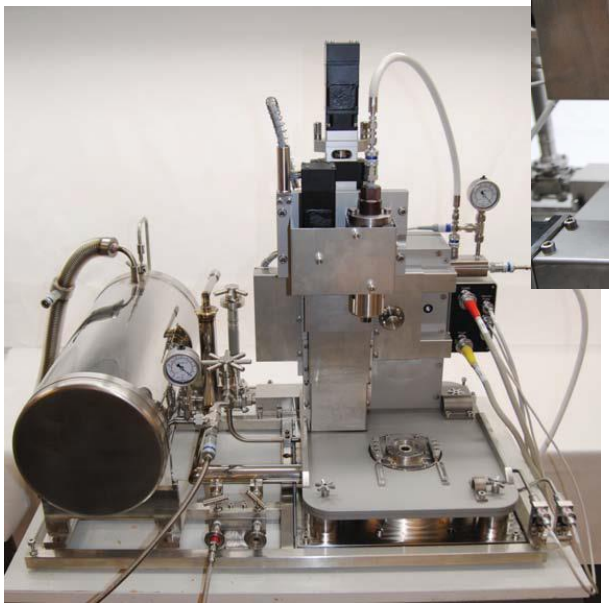
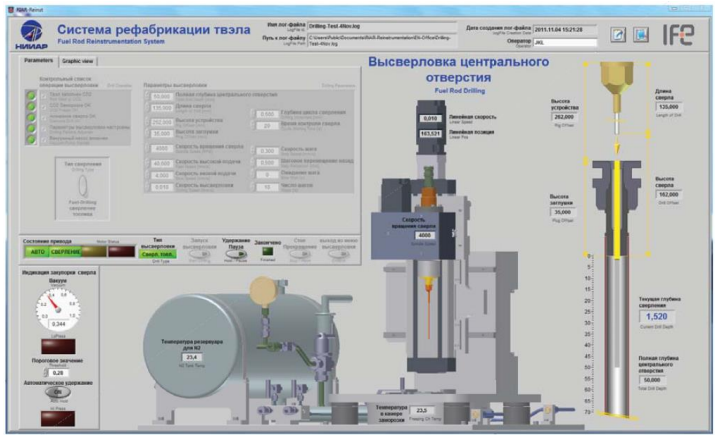
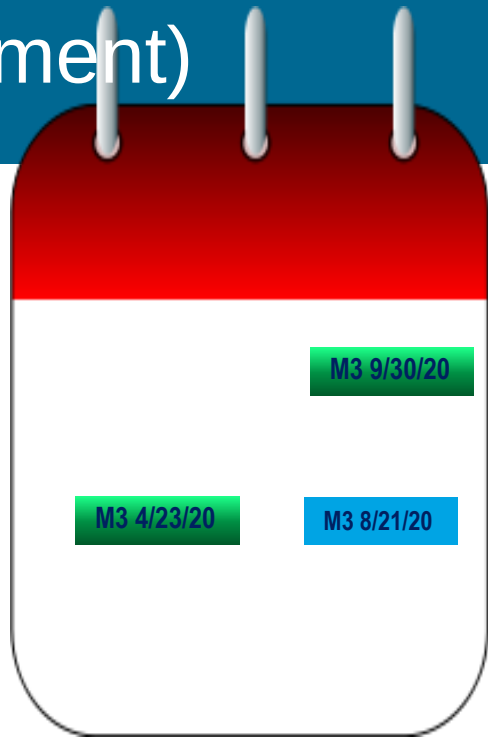




Halden equipment to instrument pre-irradiated fuel rods

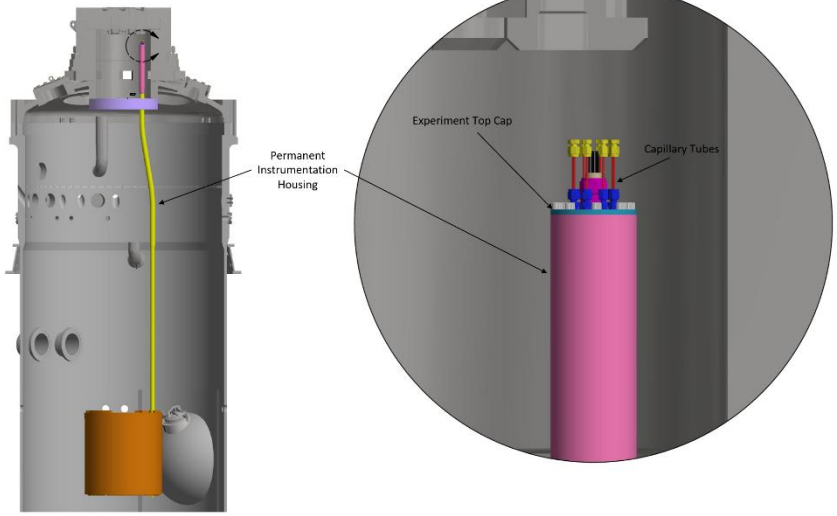
Irradiation test (Instrumentation deployment)

- FY20 activities:
  - Develop an irradiation vehicle for instrumentation test in ATR
    - part of NEET-ASI strategic plan, coordinated with AFC iloop project
  - Fabricate ATR-C neutron flux sensor test – ready to insert
    - Coordinated with iloop project (booster performance validation)
  - Instrumentation performance demonstration in TREAT
  - Optical fiber probes test in AGC



- FY19 accomplishments:
  - Deployed instrumentation for DISECT experiment in BR2 (SCK) (UT, OF probes)
  - Tested neutron flux sensors in TREAT (MIMIC-N)
  - Completed design of ATR-C neutron flux sensor test
  - Performed preliminary analysis for an irradiation vehicle for instrumentation test in ATR

Halden capabilities recovery



GAIN-EPRI-NEI Sensor Technologies for Advanced Reactors Workshop

- GAIN, EPRI, NEI workshop to exchange information among advanced nuclear technology developers, commercial instrument suppliers, and sensor researchers from DOE national laboratories, universities, and industry
- GOAL: Obtain nuclear industry input related to measurement requirements and needs for advanced reactor concepts to inform applicable DOE research programs

Workshop information
Date: Summer 2020 (TBD)
Location: Energy Innovation Laboratory (EIL), Idaho Falls, ID
Participants: ~70

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