

In-Core Sensor Advances Through NSUF Access

Joshua Daw
Joshua.Daw@inl.gov
Research Scientist
March 7, 2024

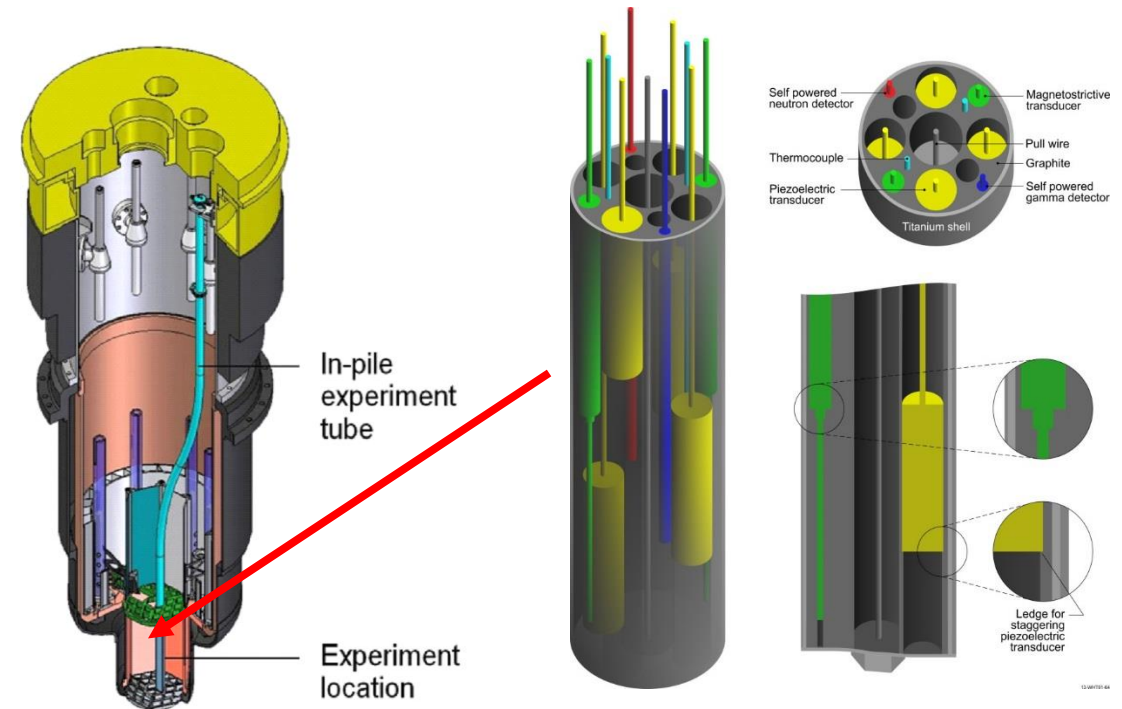
Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy



Idaho National Laboratory

Ultrasonic Transducer Irradiation (ULTRA)

- Goal
 - Enable in-core use of ultrasonic sensor technologies for monitoring a wide range of parameters in material and test reactors
- Experiment (MITR)
 - ~18 months, 8.8×10^{20} n/cm² fast
- Magnetostrictive Transducers (INL)
 - Galfenol, Remendur
- Piezoelectric Transducers (PSU)
 - AlN, ZnO, BiTiO



Massachusetts Institute of Technology
Nuclear Reactor Laboratory



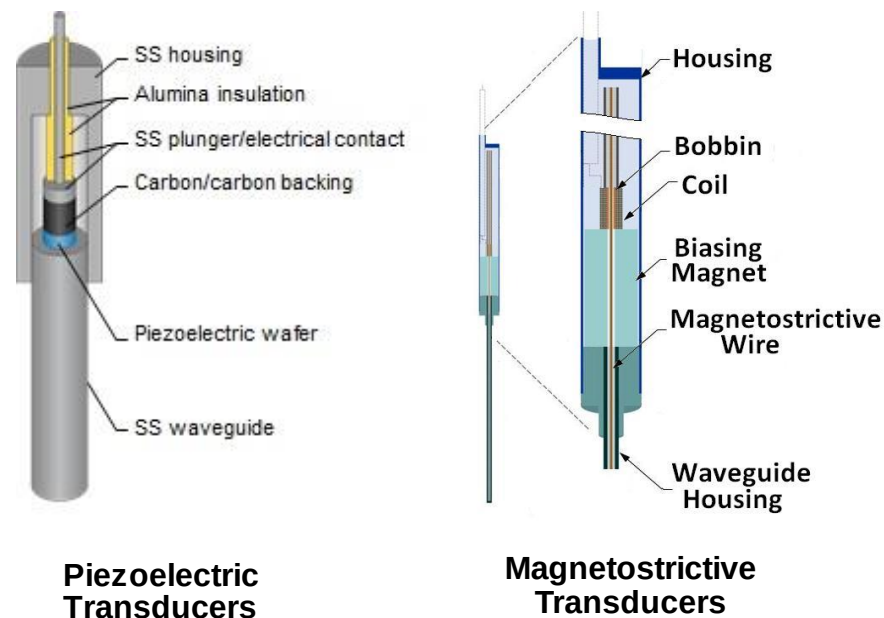
Argonne
NATIONAL LABORATORY



Pacific Northwest
NATIONAL LABORATORY

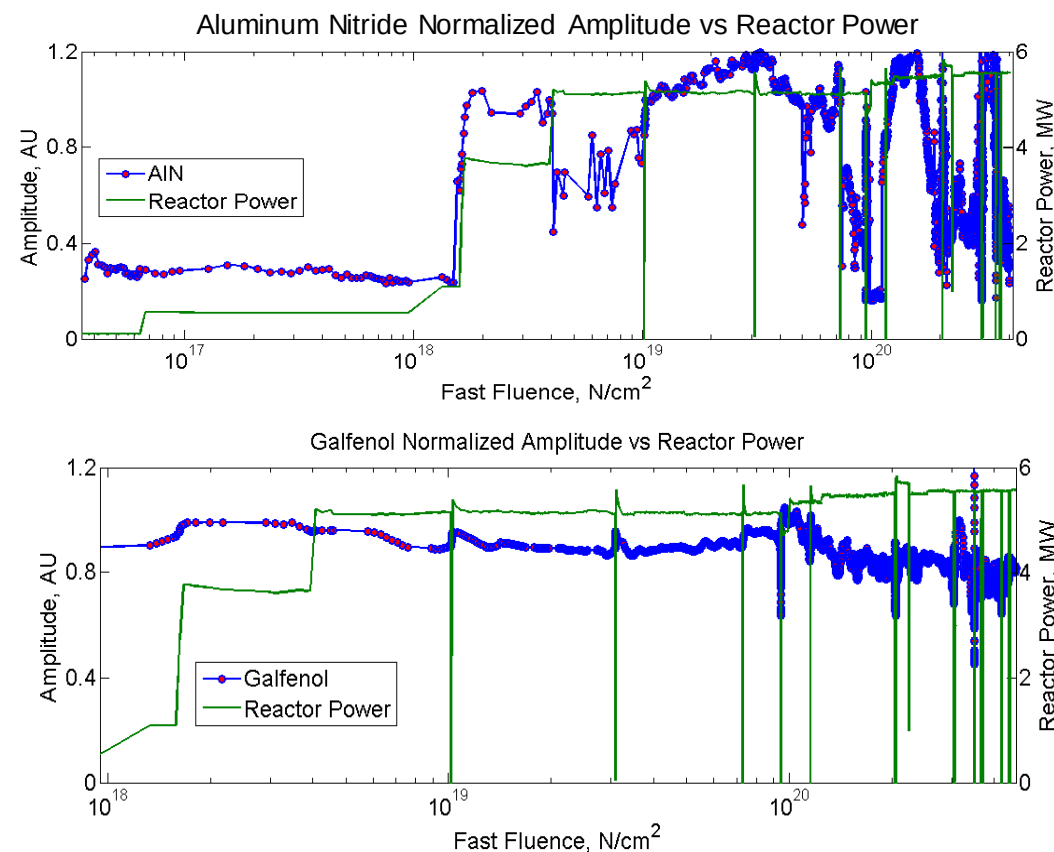
IDAHO NATIONAL LABORATORY

ULTRA-Outcomes



AlN, Galfenol, Remendur found to be highly radiation tolerant

- Large expansion in research into piezoelectric and magnetostrictive in-core applications



Basis for multiple sensors

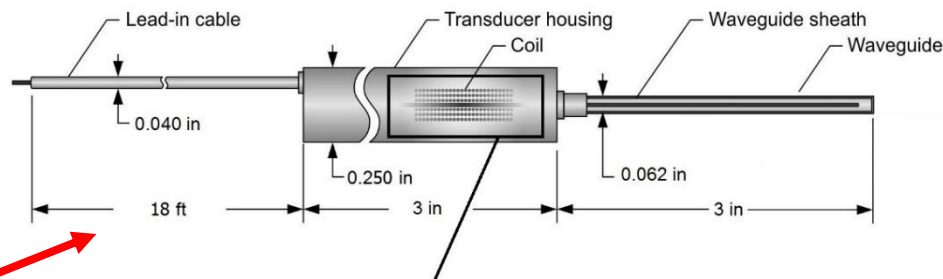
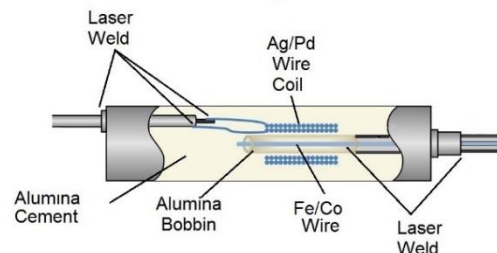
- Temperature, pressure, acoustic emission, vibration, etc.

Measurements made using acoustics

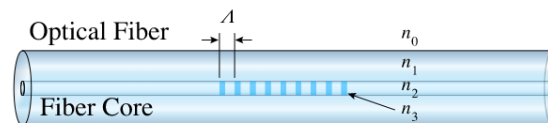
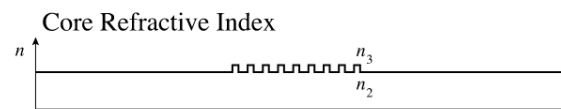
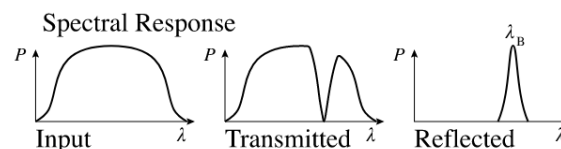
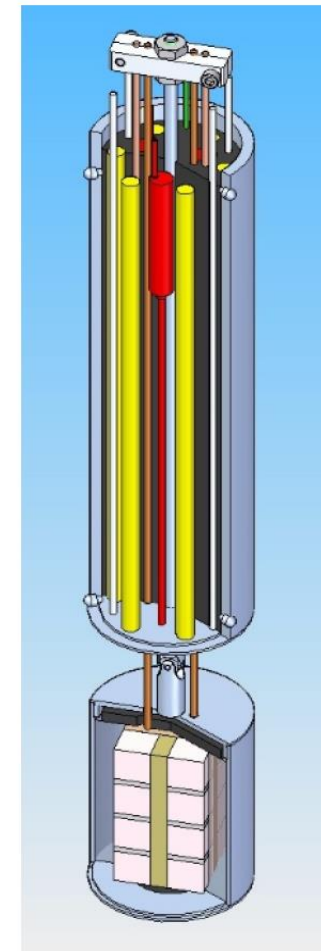
- Mechanical properties, creep, stress, grain structure, etc.

ULTRA2

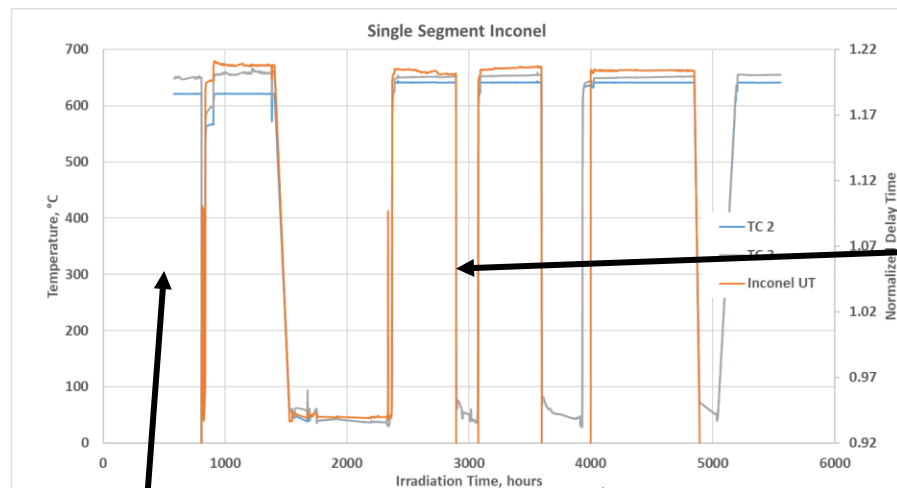
- Experiment (MITR)
 - ~11 months, 5.8×10^{20} n/cm²
 - Temperatures up to ~700 °C
- INL Ultrasonic Thermometers
 - Single segment Inconel
 - Three segment Inconel
 - Single segment titanium
- CEA Fiber Bragg Grating Sensors
 - 2 sensors, 5 nodes each
 - Point-by-Point fs laser written
- University of Pittsburgh Fiber Bragg Grating and Distributed Sensors
 - Point-by-Point fs laser written
 - Enhanced Rayleigh scattering
 - Random air line



$$v(T) = \sqrt{\frac{E(T)}{\rho(T)}}$$



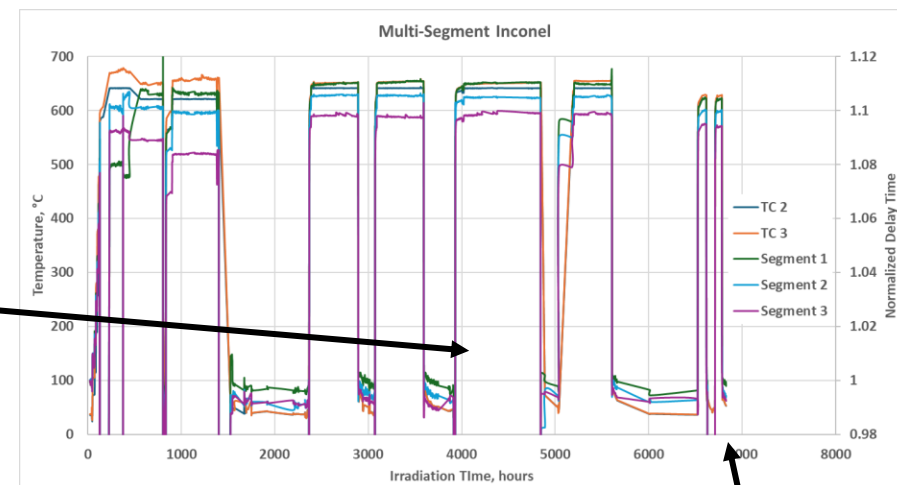
ULTRA2-Ultrasonic Thermometers



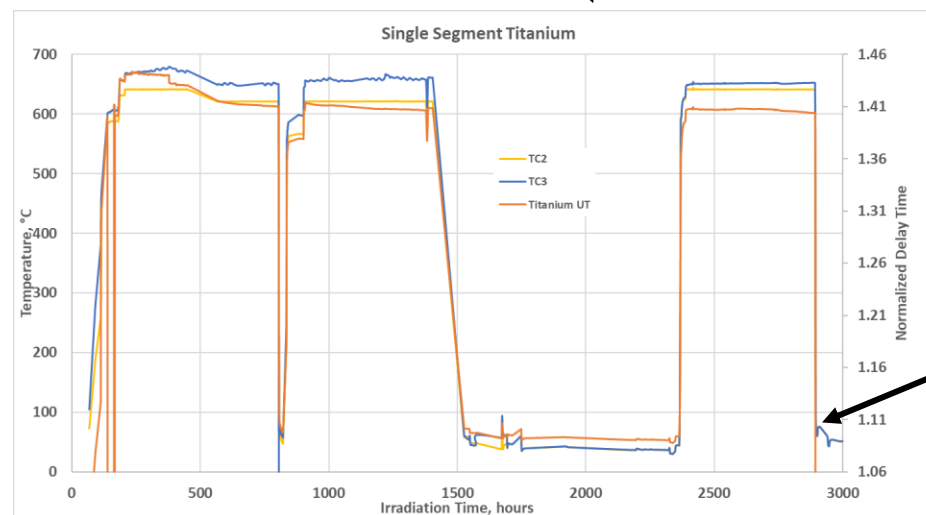
Unusable
signal during
early irradiation
due to DAQ
issues

Failure at
~5000 hours

Excellent performance
during middle irradiation
cycles

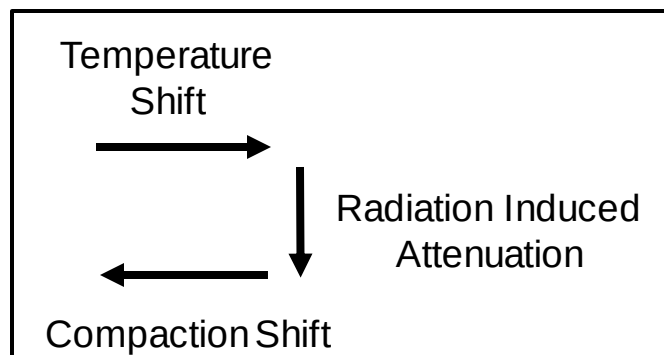


Failure at
~7000 hours

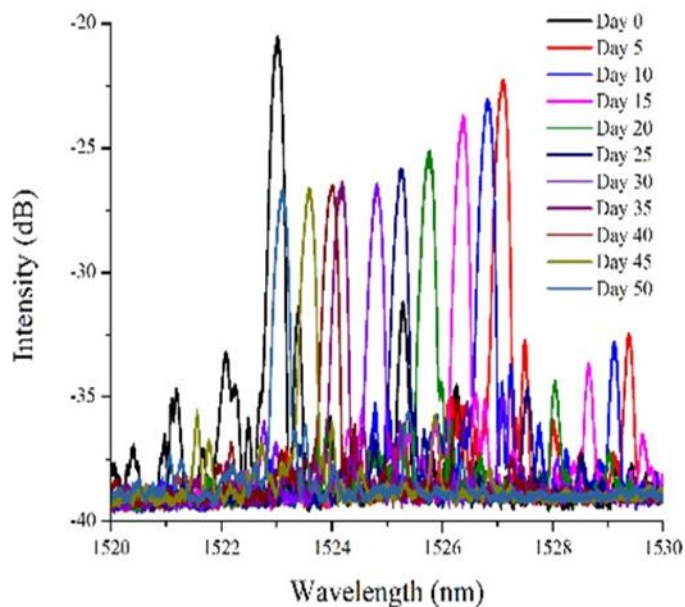
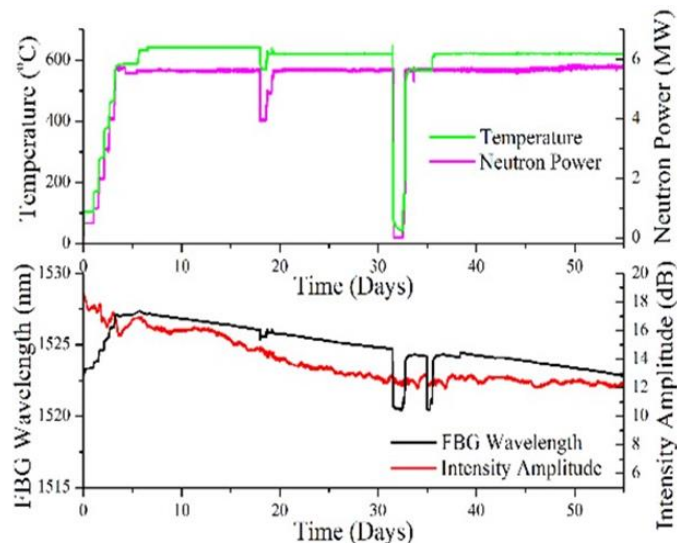


Failure at
~3000 hours

ULTRA2-Fiber Sensors



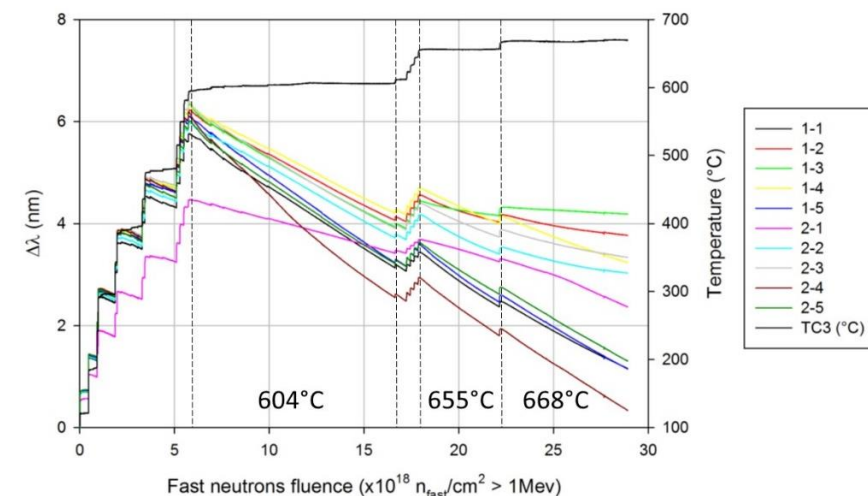
Competing Effects



U-Pitt: Attenuation and Decalibration

Outcomes

- Survivability of fibers demonstrated
- Extensive follow-on research
- Fiber sensors now routinely used in INL's TREAT reactor



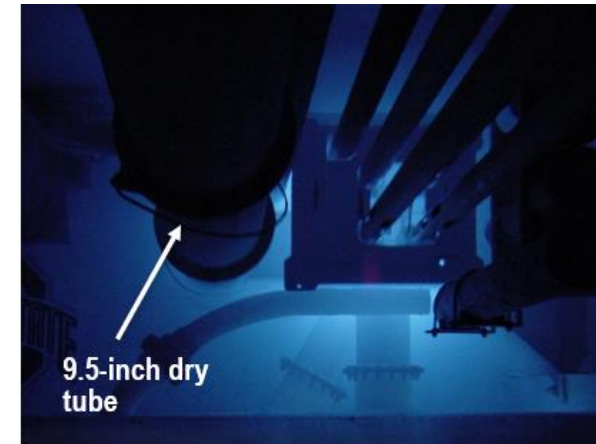
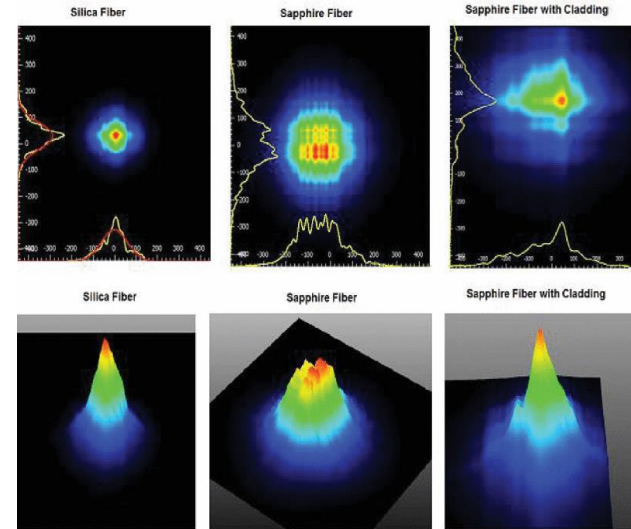
CEA: Decalibration

Basis for multiple intrinsic and extrinsic sensors

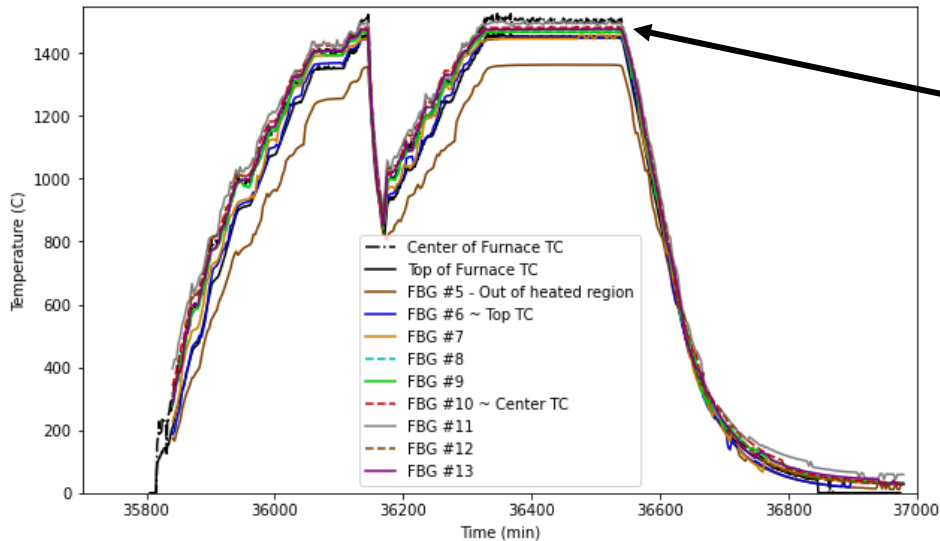
- Temperature, pressure, strain, vibration, etc.

High Fluence Active Irradiation and Combined Effects Testing of Sapphire Optical Fiber Distributed Temperature Sensors

- Goal
 - Enable the use of FBG sensors at higher temperatures and fluences than possible with silica
- 4 Cladding Irradiations (OSURR)
- High Temperature Irradiation (OSURR)
 - 1600°C
- Experiment (MITR)
 - 2 cycles at steady state
 - 3.5×10^{20} n/cm² (fast)



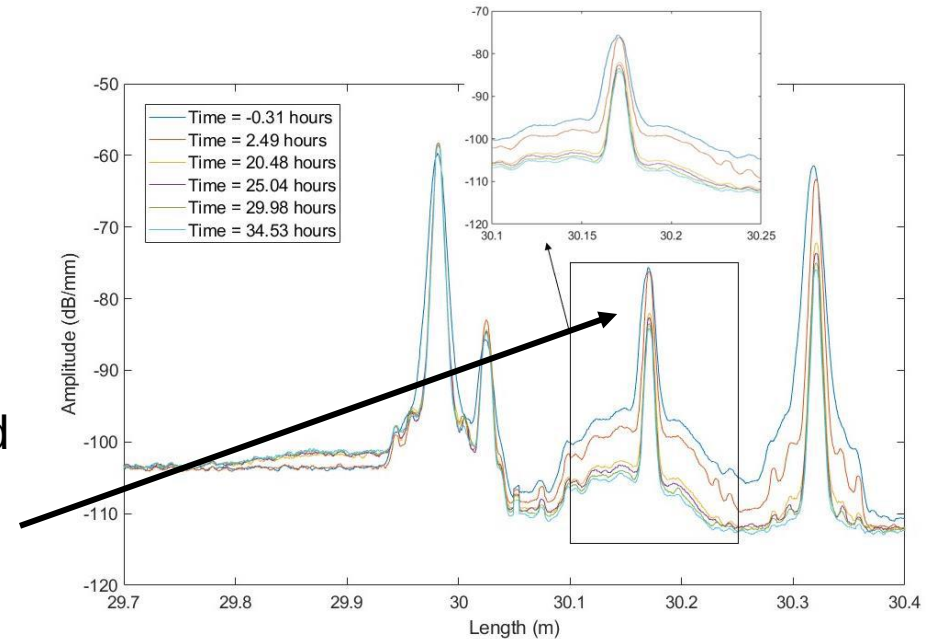
High Fluence Active Irradiation and Combined Effects Testing of Sapphire Optical Fiber Distributed Temperature Sensors



OSURR Heated Irradiation

Sapphire sensors performed better than furnace thermocouples

Radiation induced attenuation observed



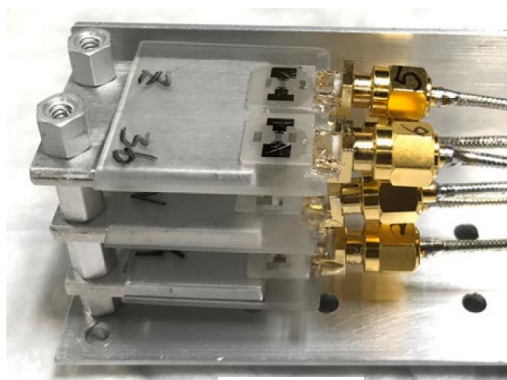
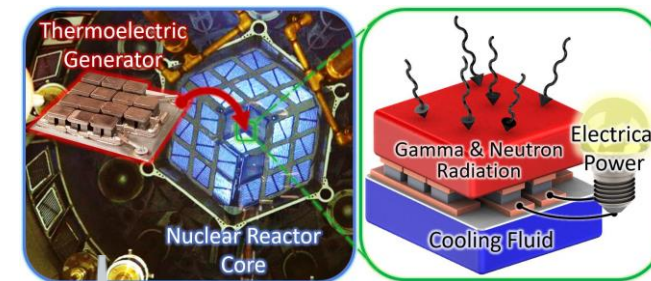
MITR Heated Irradiation

Outcomes

- Sapphire sensors are a solution for applications with temperatures above 700°C for long periods of time, or for experiment applications with any duration above 1000°C.
- OSU clad sapphire technology is being commercialized

Other NSUF Supported Activities

- ORNL led RTE
 - PIE on ULTRA piezoelectric samples
 - Tested d33 in BiTiO material
 - Verified accuracy of degradation that was based on pulse/echo amplitude measurements
- OSU led irradiation
 - Tested AlN and LiNbO surface acoustic wave devices under neutron irradiation with temperature control-frequency domain analysis
 - Reversible effects of temperature and radiation observed
- Notre Dame led irradiation
 - Two irradiation campaign in MITR
 - Tested nanostructured bulk half-Heusler (HH) thermoelectric generators
 - Irradiation effects decreased efficiency, but saturate at useful levels
 - Can be used for self-powered sensors

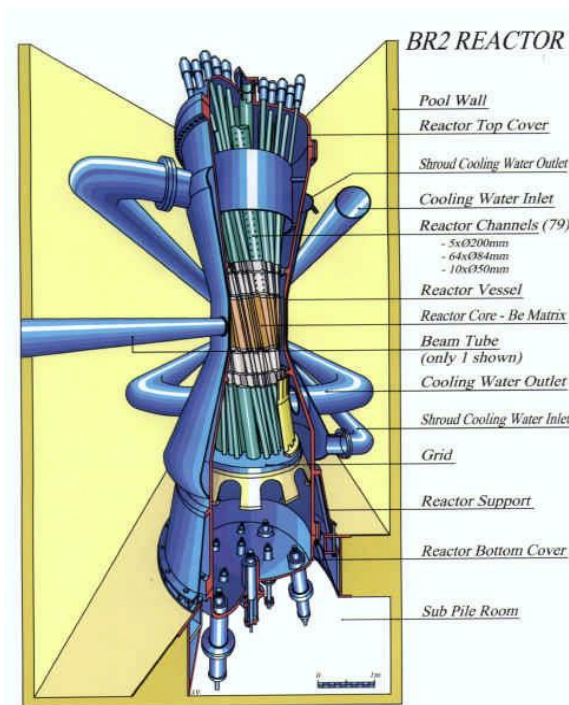


 Massachusetts Institute of Technology
Nuclear Reactor Laboratory

Upcoming Irradiations

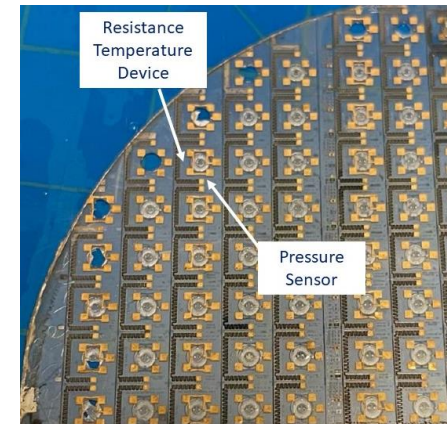
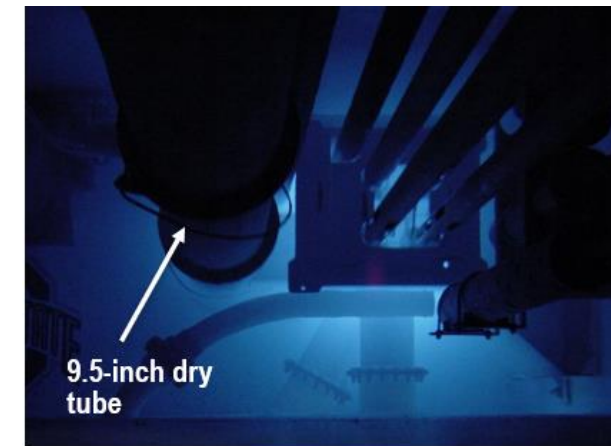
Disc Irradiation for Separate Effects Testing with Control of Temperature (DISECT)

- Consists of two irradiations in BR2
 - One with U-Zr Fuel specimens
 - One with U-Mo Fuel specimens
- U-Zr capsule contains 18 pucks
 - Target design temperatures range from 550 – 750 °C
- INL will provide one multi-segment UT and two optical fiber sensors



Rapid Turnaround Experiment-Irradiation of NASA developed Piezoresistive Pressure Sensors

- Multiple short-term irradiations in OSURR
- Sensor was developed for Venus probe and may be used for Fission Surface Power reactor on moon and Mars





For additional questions
or contact information,
please contact me at
joshua.daw@inl.gov

*Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy.
INL is the nation's center for nuclear energy research and development, and also performs research
in each of DOE's strategic goal areas: energy, national security, science and the environment.*