U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Science User Facilities

INL High Temperature Test Laboratory NSUF Activities

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NSUF Nuclear Science User Facilities

Annual Review
Germantown, MD
March 2, 2016

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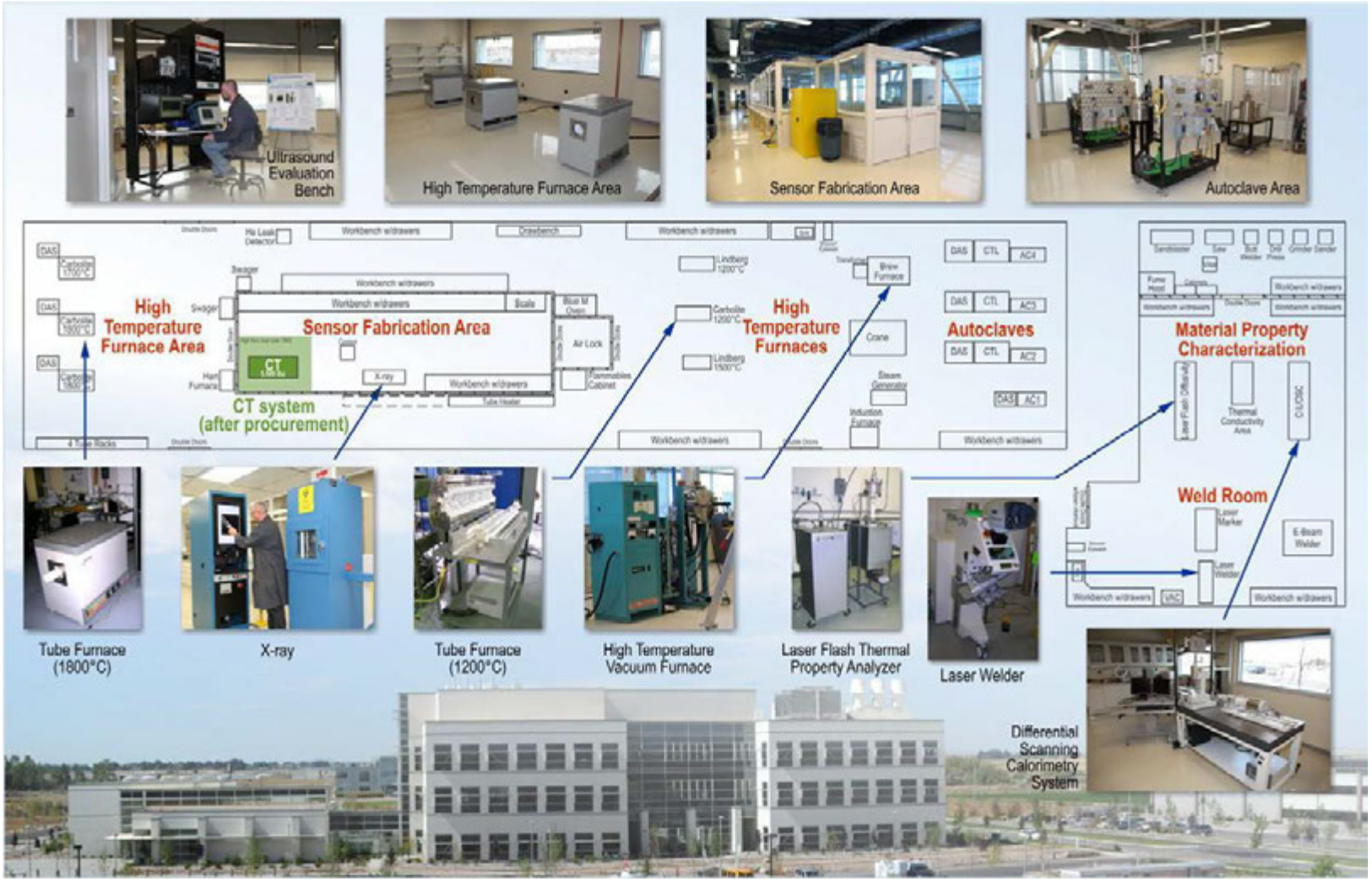
New Energy Innovation Laboratory (EIL) Enhances HTTL In-pile Instrumentation Development Capabilities

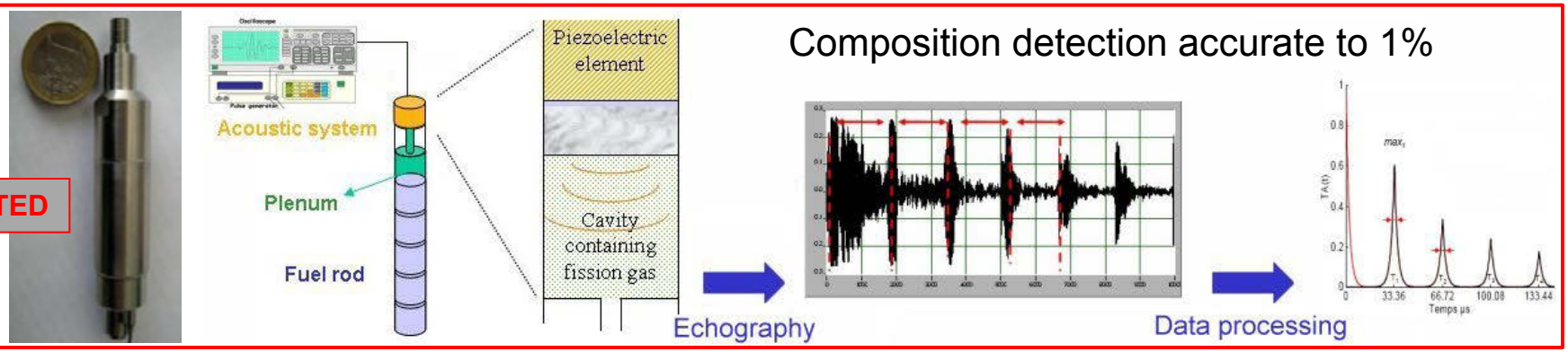


Outline of Presentation

- **Ultrasonic Transducer Irradiation Test (ULTRA)**
  - INL, PNNL, ANL, PSU, MIT, CEA, Bechtel-Bettis
- **ULTRA 2**
  - INL, MIT, CEA
- **SiC Processing Development**

Ultrasonic Sensors Offer Potential Improvements Over Existing Sensors As Well As New Measurements

- **Industrial applications demonstrate ultrasound-based sensors offer unprecedented opportunities for measuring numerous parameters**
  - Temperature (up to 3000 °C) [Some prior use, current development]
  - Fission gas composition and pressure [Developed by CEA]
  - Coolant level, flow
  - Dimensional changes (down to ~1 μm) [Waveguide method in development]
  - Microstructure changes (e.g., grain/pore development, crack initiation and growth, etc.) [PIE fuel porosity measurement in development]
  - In-service component inspection
  - Imaging



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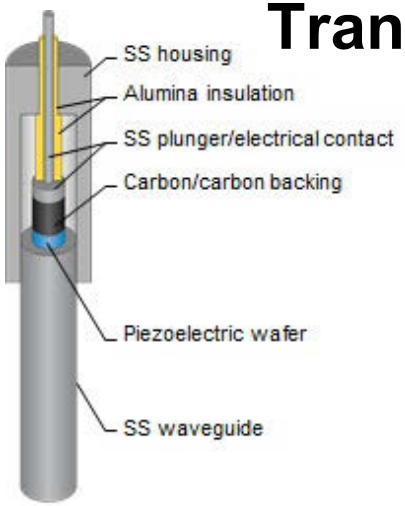
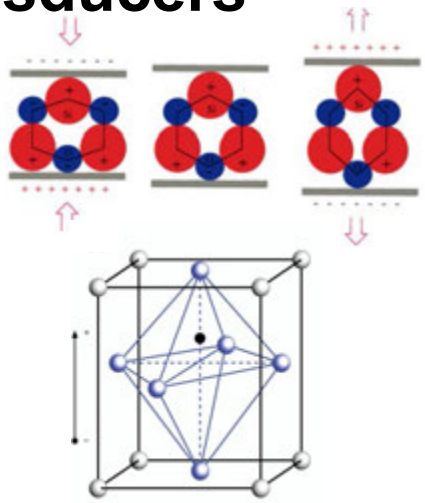
Selected Transducer Technologies

Piezoelectric Transducers





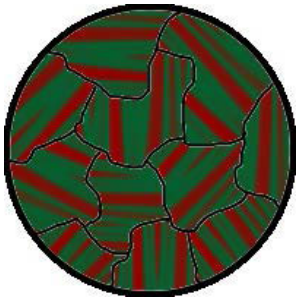
Included Piezoelectric Materials

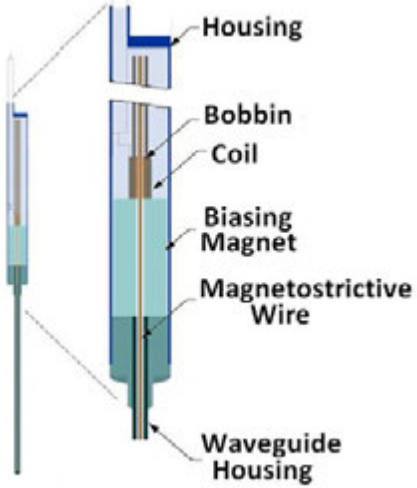
- Bismuth Titanate
- Aluminum Nitride
- Zinc Oxide

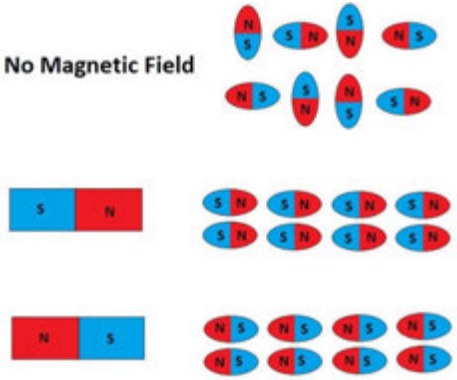
Magnetostrictive Transducers

Included Magnetostrictive Materials

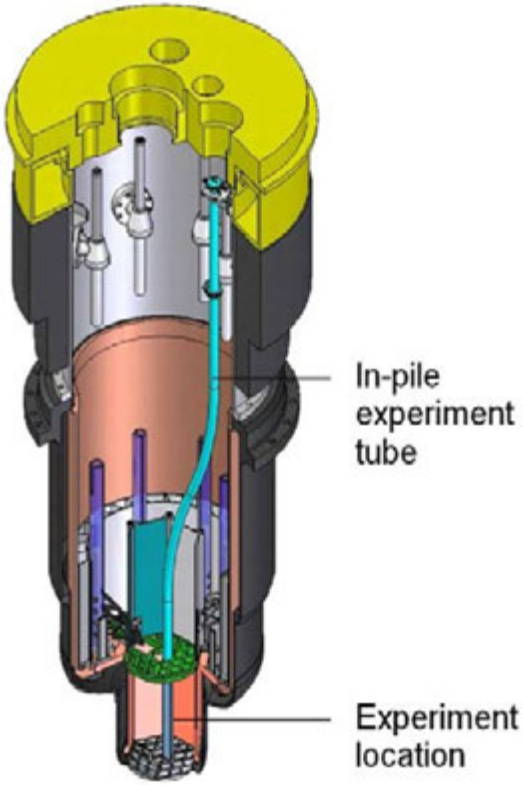
- Remendur
- Galfenol
- Arnokrome 4 and 5 (loose)







Massachusetts Institute of Technology Research Reactor (MITR)



- **Licensed for 6 MW operation**
- **Max. in-core volume ~ 46 mm ID x 610 mm long**
- **Neutron Flux (n/cm^2-s):**
  - Thermal: ~3x10^{13}
  - Fast: up to 1x10^{14} (E>0.1 MeV)
- **Temperature control via He/Ne gas mix**

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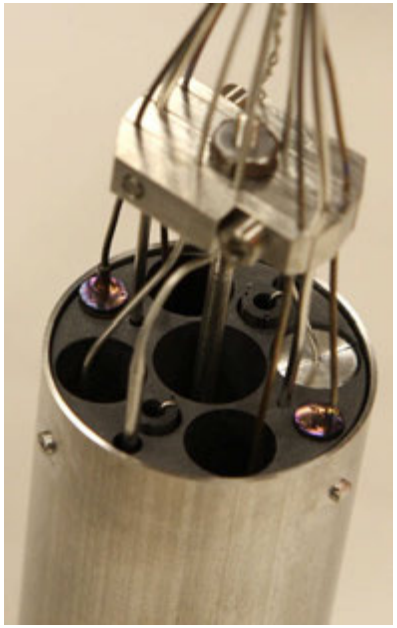
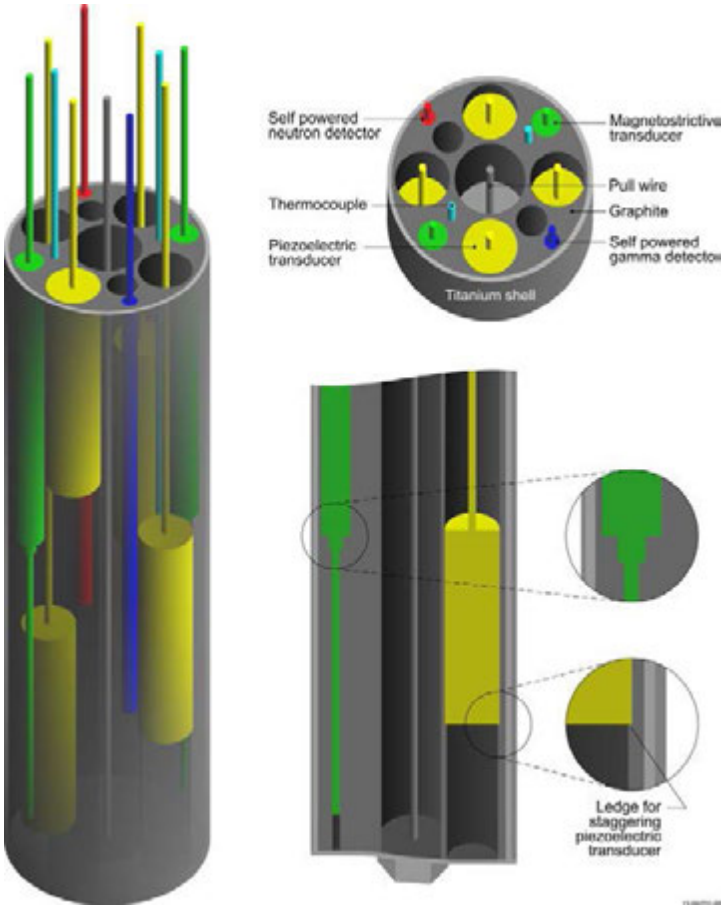
ULtrasonic TRAnsducer (ULTRA) Irradiation Test Capsule





Included Sensors:

- 2 Type-K TCs
- 1 V-SPND
- 1 Pt-SPGD
- Melt Wire Capsule (5 wires)
- Flux Wires

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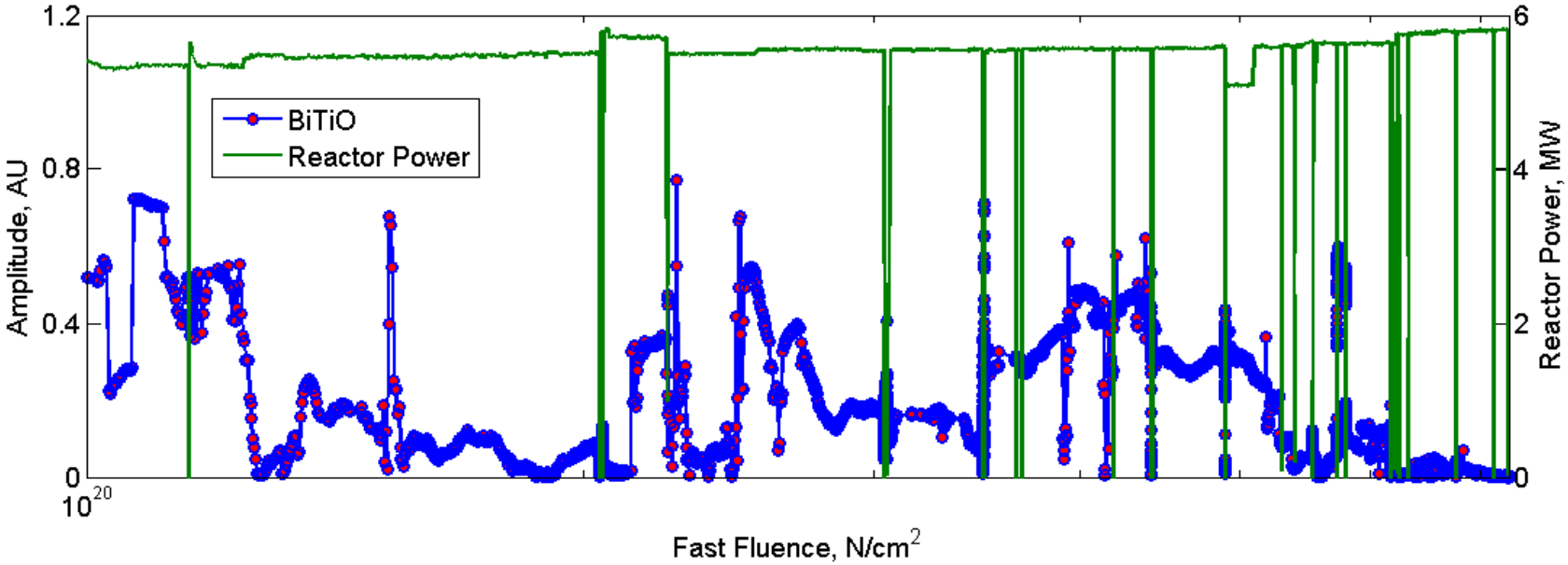
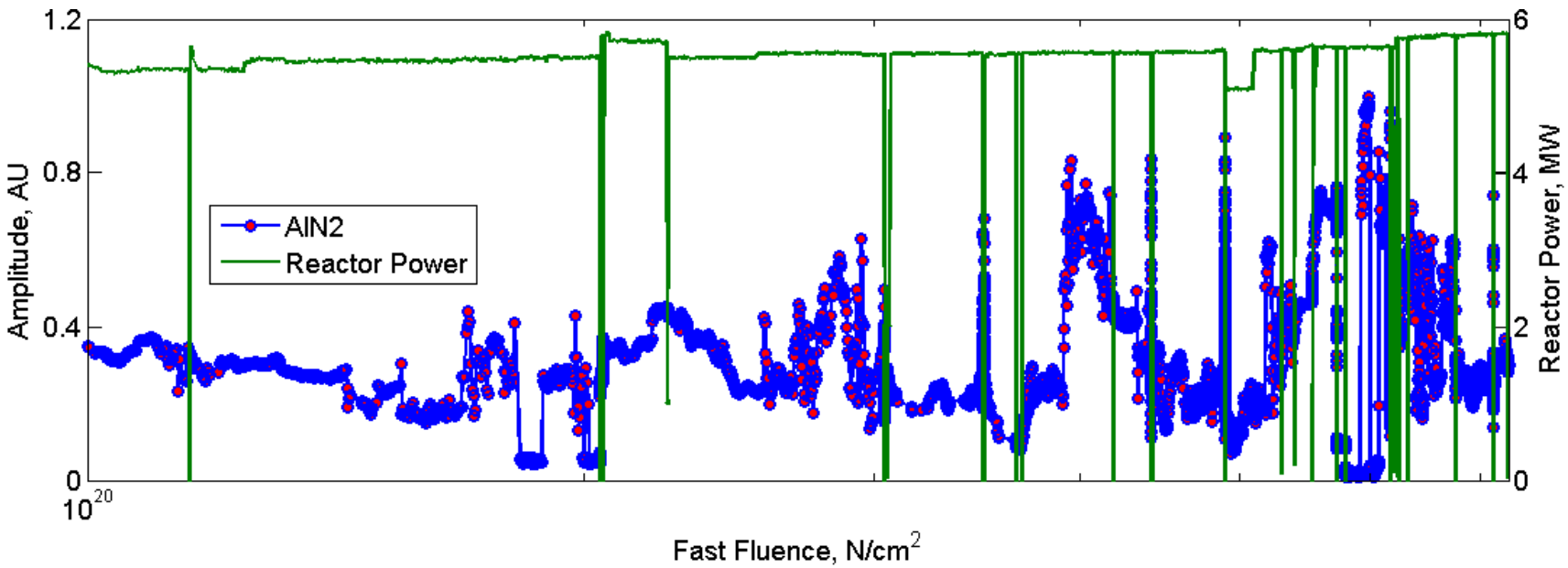
ULTRA Results: BiTiO



- Early irradiation performance shows expected amplitude loss as compared with prior tests.
- Recoveries observed during shutdowns. Gradual decreases follow during normal reactor operation.
- Late irradiation data shows total loss of signal

ULTRA Results: AIN



- **Maximum signal amplitude shows little change with irradiation**
- **Coupling and piezoelectric efficiency change as functions of temperature**
  - Maximum signal increasing slightly over course of irradiation
  - Rapid amplitude changes due to sudden changes in coupling during temperature transients

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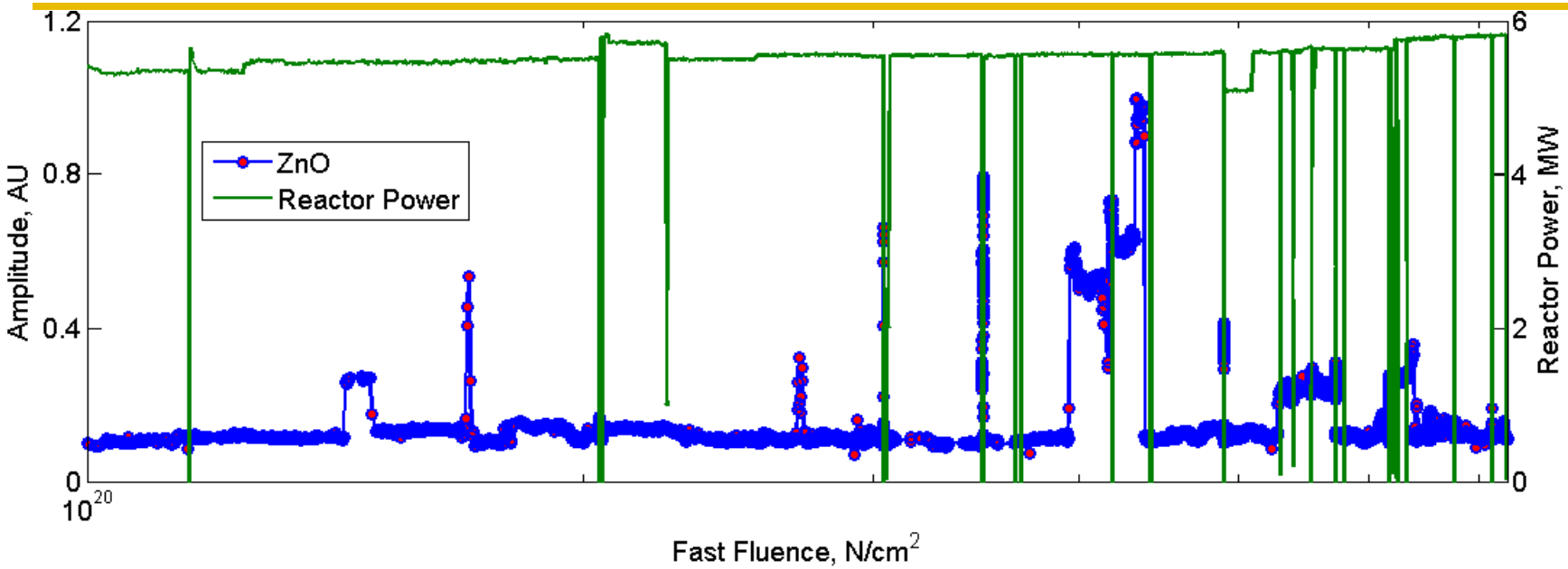
ULTRA Results: ZnO



- Electrical failure experienced during reactor start-up.
- ZnO loses piezoelectricity at temperatures over ~190 °C. Test temperatures are over 400 °C.
- Sporadic signals received during shut-downs indicate piezoelectric properties are maintained.

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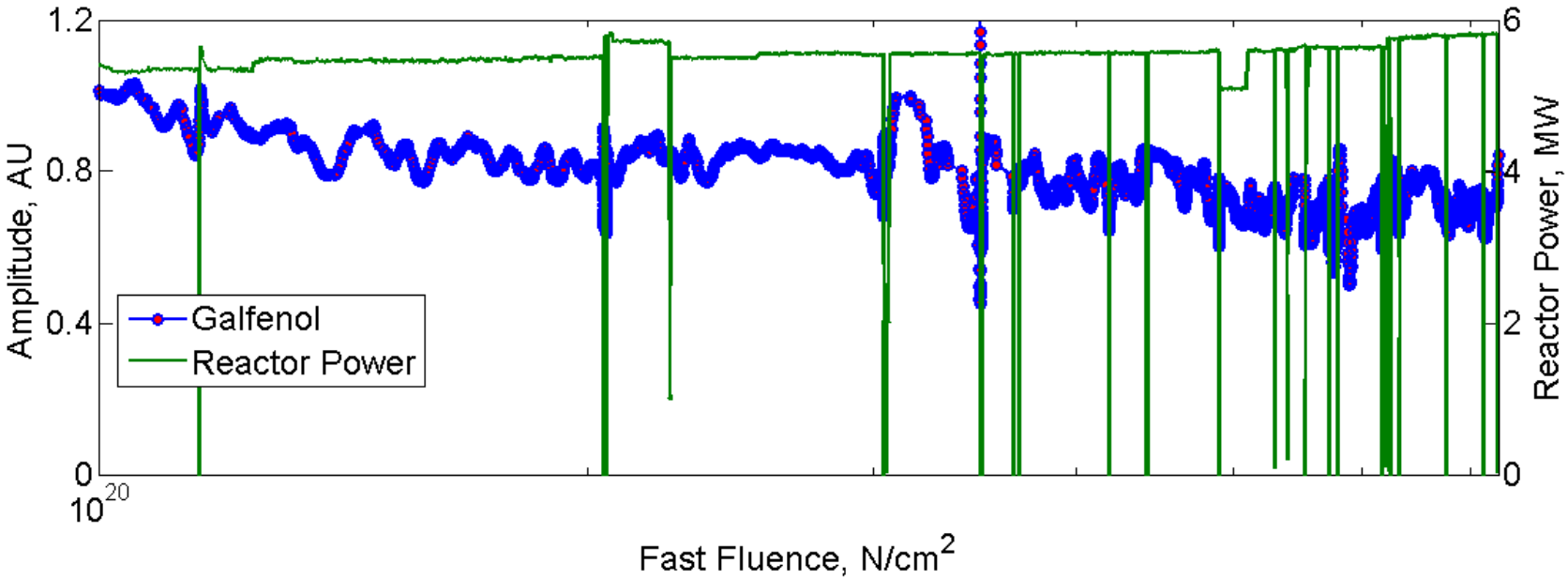
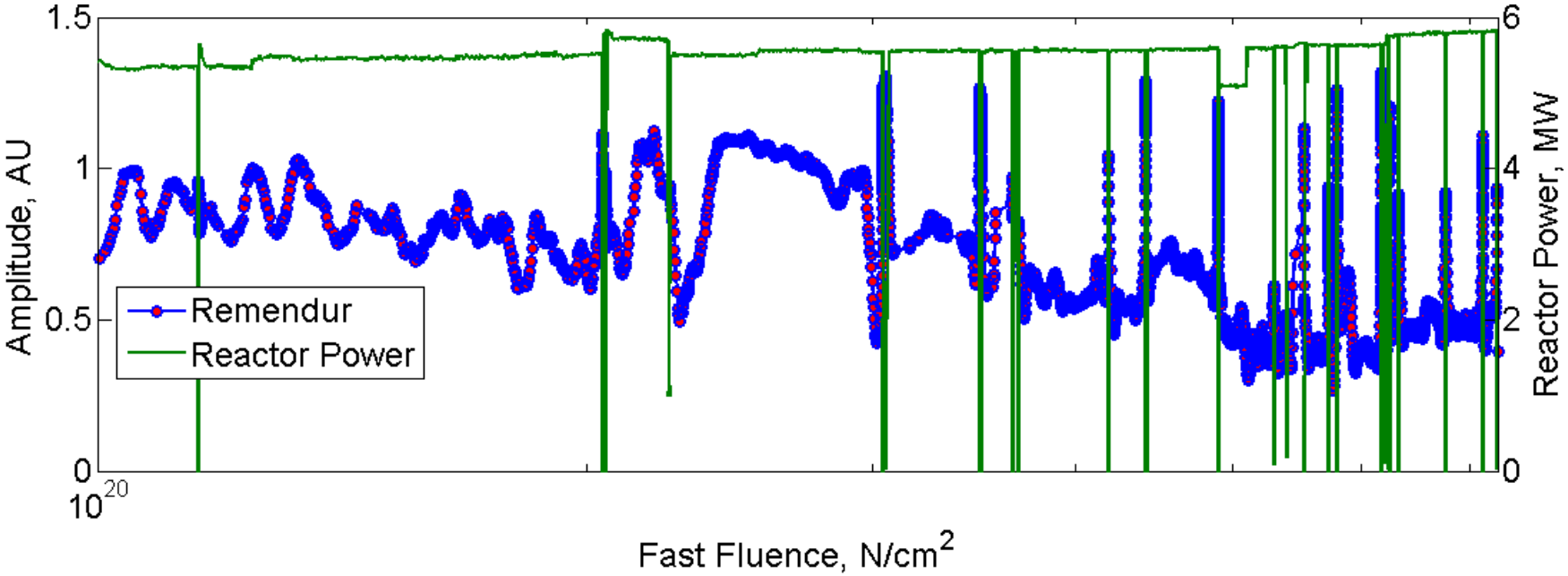
ULTRA Results: Galfenol



- **10% signal loss during first reactor cycle**
- **~30% total loss since increase to full reactor power**
- **Some temperature effects evident**
  - Sudden changes to signal strength during SCRAMs
- **Retention of properties verified during PIE**

ULTRA Results: Remendur



- **Slow signal loss during first cycle**
- **Steady loss after increase to full reactor power**
- **Significant effect of temperature changes observed**
  - Changes to waveform shape caused by binding of wire
  - Strong recoveries during shutdowns indicates magnetostrictive effect intact
- **Retention of properties verified during PIE**

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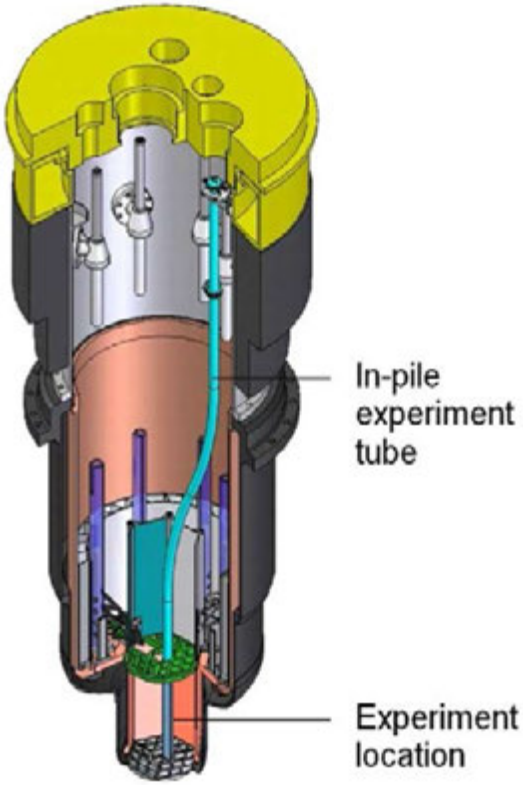
Conclusions

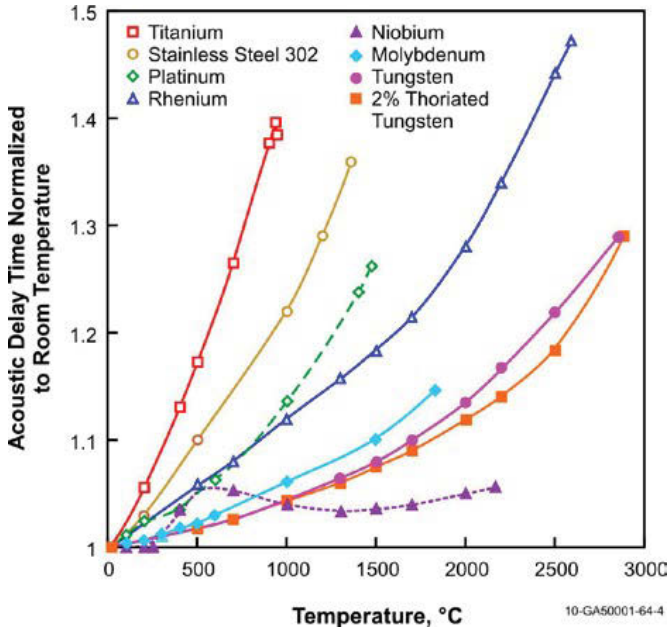
- Both magnetostrictive and piezoelectric transducers have been tested
- Higher fast fluence reached than prior tests ($8.8 \cdot 10^{20}$ reached)
- Highly instrumented for both temperature and flux
  - Real time data to correlate performance
- Neutron tolerant candidates of both types identified
  - Galfenol, Remendur
  - AlN, ZnO, BiTiO (short term irradiation)
- Test provides enablement of future ultrasonic sensor development and deployment

ULTRA 2

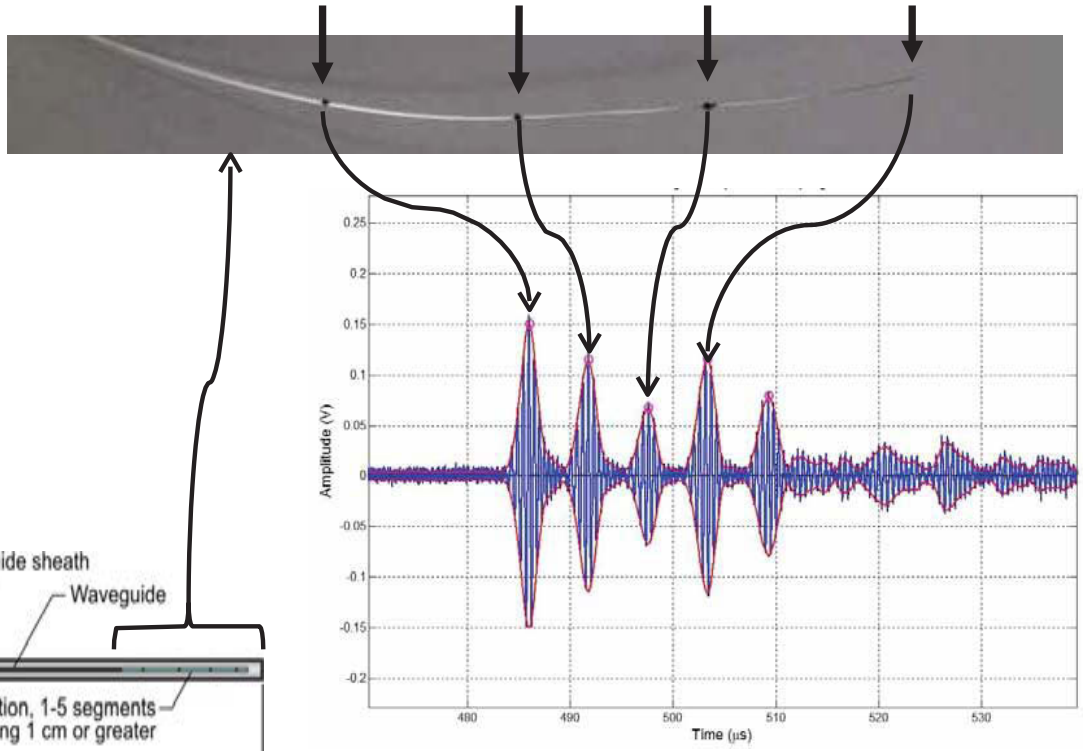


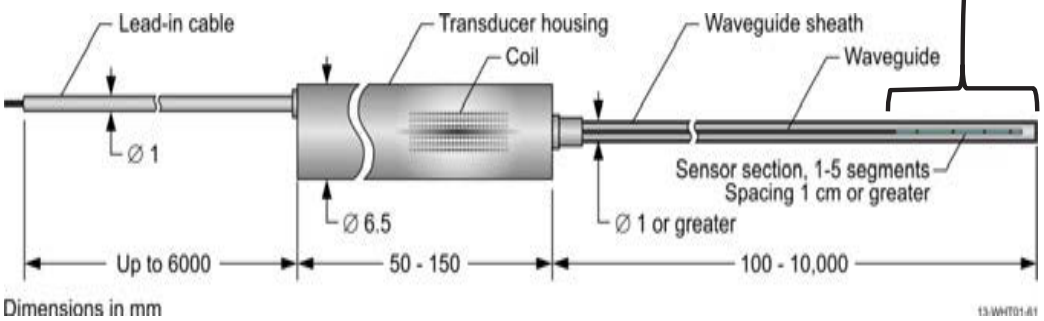
- **Ultrasound based sensors developed/improved using results from ULTRA**
- **Ultrasonic thermometer**
  - Developed by INL
- **Acoustic gas monitor**
  - Developed by CEA
  - Possible issue with use of AGM in ULTRA 2

ULTRA-2: Ultrasonic Thermometer



3-segment UT sensor formed from 0.25 mm wire, reflectors created by points of added mass (other methods possible)



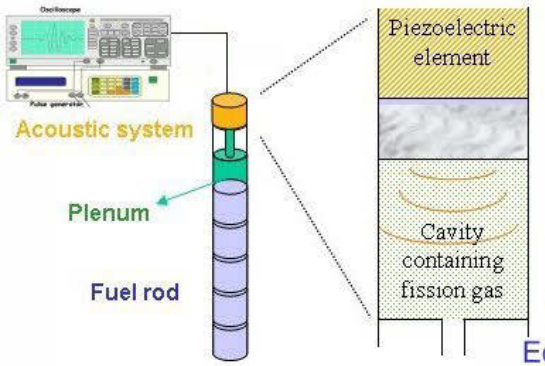


UT consists of transducer, lead-in waveguide, and multi-segment sensor

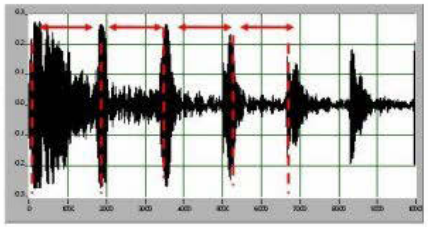
Reflections generated at acoustic reflectors and end of wire allow measurement of average wire temperature between points

ULTRA-2: Acoustic Gas Monitor

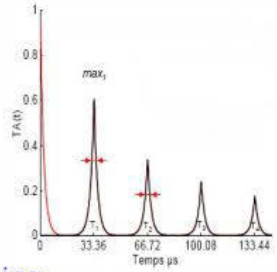
PATENTED



Composition detection accurate to 1%



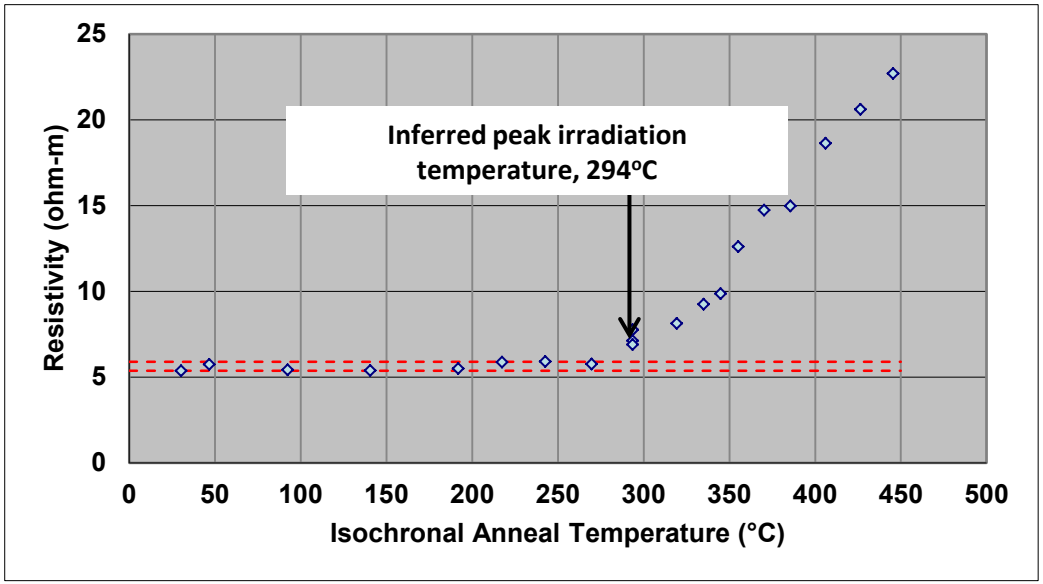
Echography

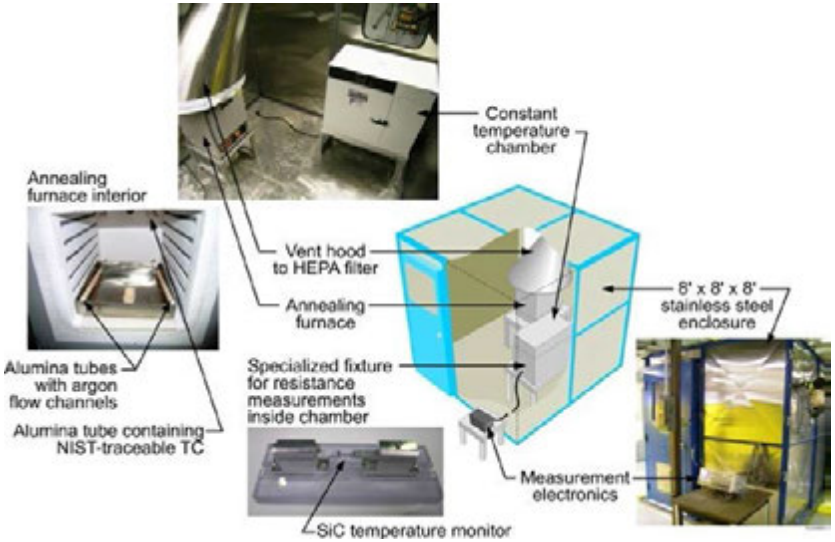


Data processing

- **CEA Developed and Patented Sensor**
- **Capable of simultaneous measurement of fission gas composition and pressure (in theory)**
- **CEA is unlikely to have the AGM ready for MIT insertion**
- **Possible replacement in test by fiber optic temperature sensor**

Silicon Carbide Temperature Monitor Post Irradiation Analysis

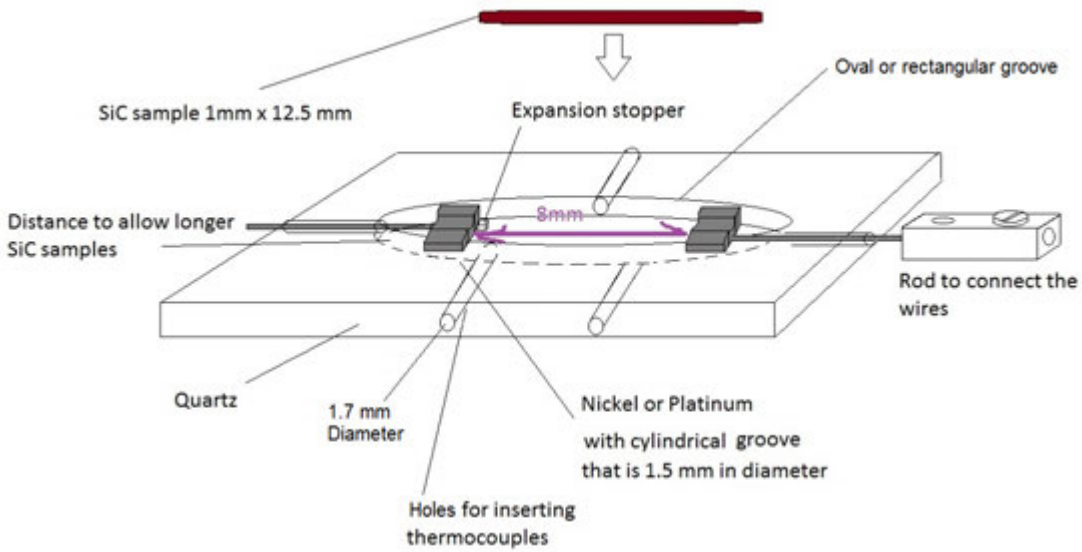




1 x 1 x 10 mm

- **Small (1 mm x 1 mm x 10 mm bar or 1 mm x 10 mm rod) monitors of high density CVD SiC**
- **SiC monitors heated for 30 minutes in furnace with NIST-traceable thermocouples**
- **Specialized fixturing developed for resistance measurements**
- **Measurements made in constant temperature chamber**
- **Estimated accuracy of 20 ºC for wide range of temperatures (200 – 800 ºC) and doses (1.1 to 8 dpa)**

Silicon Carbide Temperature Monitor Post Irradiation Analysis Improvement



- **Continuous resistivity and temperature measurement during heating and cooling between 200 and 800 ºC**
- **Multi-sample batch processing**
  - Current equipment can accommodate up to 4 monitors

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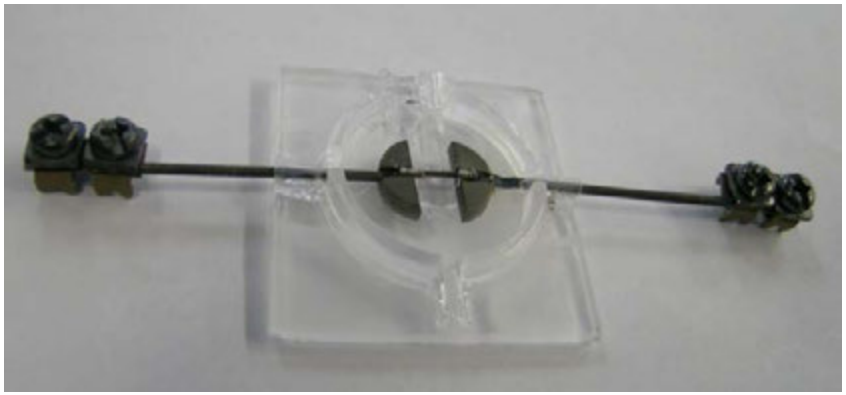
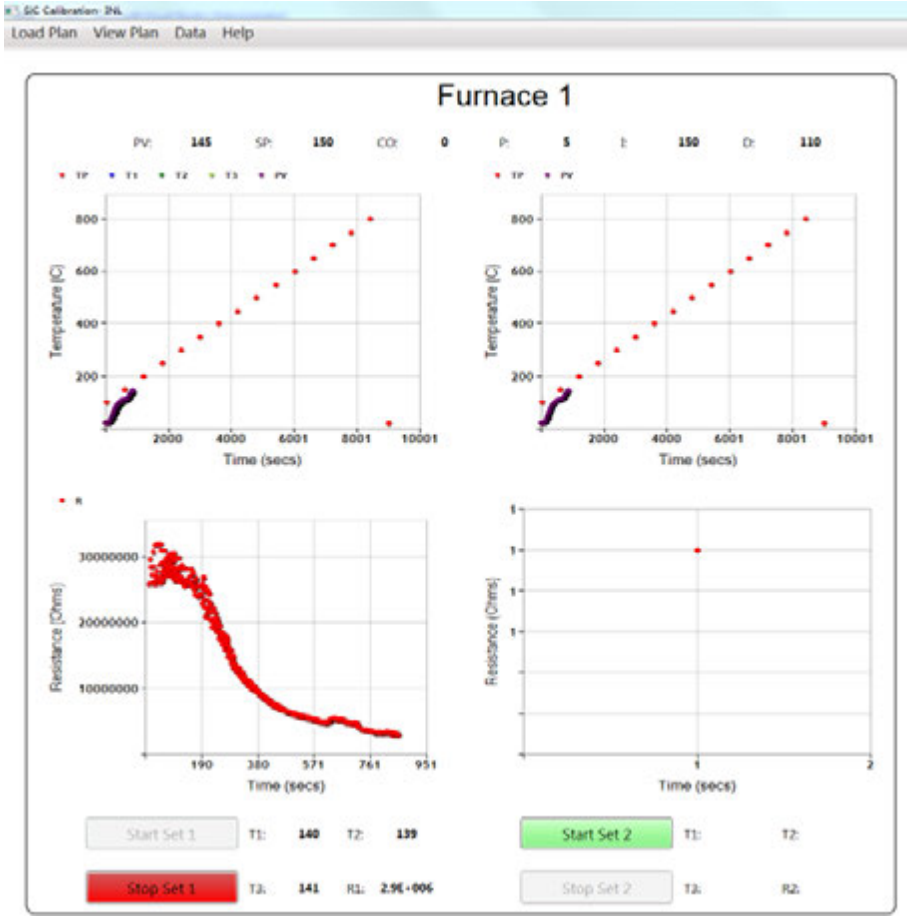
Preliminary Test Results





- **System operation verified**
- **Unirradiated SiC resistivity measured**
- **Still to evaluate:**
  - Irradiated sample measurement
  - Potential accuracy
  - Need for unirradiated reference sample

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