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Nuclear Energy Enabling Technologies (NEET)

Advanced Sensors and Instrumentation (ASI) Annual Project Review

Irradiation Testing of Ultrasonic Transducers

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INL

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Project Overview

Goal

- Enable in-pile use of ultrasonic sensor technologies for monitoring a wide range of parameters in material and test reactors

Participants

» Joshua Daw, Joy Rempe, and Joe Palmer**; Idaho National Laboratory
» Hual-Te Chien; Argonne National Laboratory
» Pradeep Ramuhalli; Pacific Northwest National Laboratory
» Bernhard Tittmann and Brian Reinhardt; Pennsylvania State University
» Ben Wernsman; Bechtel Bettis, Inc.*
» Gordon Kohse and Lin-Wen Hu; Massachusetts Institute of Technology**
» Jean-François Villard; Commissariate a l'energie atomique*

DOE-R&D programs benefitting from this work

- FCRD, ATR NSUF, ARC, SMR, NGNP, LWR/Reactor Safety (new), and LWRS/ Industry Programs

*Self-funded; ** ATR-NSUF funded

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Technology Impact

- **Industrial applications demonstrate ultrasound-based sensors offer unprecedented opportunities for measuring numerous parameters**
  - Temperature (up to 3000 °C)
  - Fission gas composition and pressure
  - Water level
  - Coolant flow
  - Dimensional changes (down to ~1 μm)
  - Microstructure changes [e.g., grain/pore development, crack initiation and growth, etc.]
  - In-service component inspection
- **Three-year project addresses cross-cutting areas hindering in-pile ultrasonic sensor deployment**
  - Transducer irradiation survivability
  - Signal processing

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Research Plan

- **FY 2012: $325,000**
  - Transducer Irradiation
    - Identify needs from DOE-NE programs and define irradiation test program
    - Identify candidate transducers
    - Begin test rig design
  - Signal Processing Enhancement
    - Identify signal processing needs to meet DOE-NE program requirements
    - Identify hardware requirements
- **FY 2013: $334,000**
  - Transducer Irradiation
    - Prepare and review test plan summarizing proposed irradiation
    - Fabricate transducers for irradiation and transmit to MIT
    - Collaborate on ATR NSUF irradiation deploying test rig and monitoring data from test rig
- **FY 2014: $ 316,000**
  - Transducer Irradiation
    - Validate data and data interpretation.
    - Develop recommendations based on data from irradiation test.
  - Signal Processing Enhancement
    - Develop framework for integration to common platform
    - Develop and validate signal processing algorithms for selected parameters

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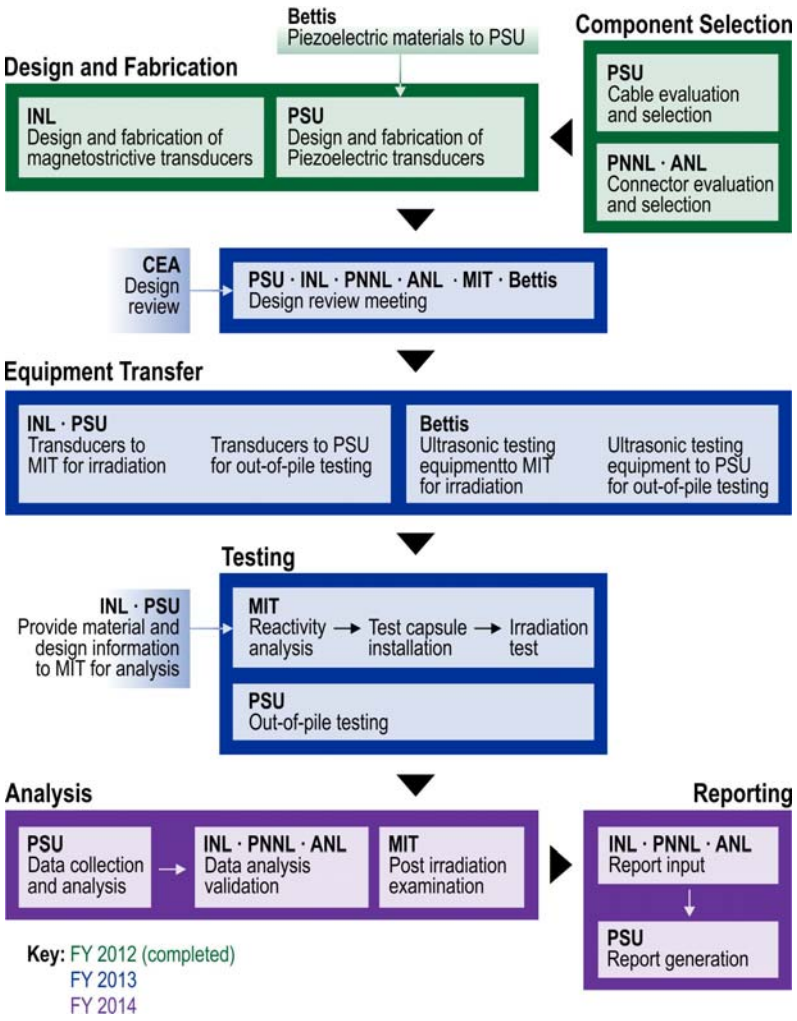
FY 2012 Accomplishments



- **Transducer Irradiation**
  - Leverage PSU-led irradiation funded by ATR NSUF at MITR
  - Identified magnetostrictive and piezoelectric transducer materials for irradiation
  - Began capsule design and component selection
- **Signal Processing Enhancement**
  - Input gathered from cognizant program leads
  - Identification of parameters of prime interest
  - Developed hardware requirements
- **Issued "NEET In-Pile Ultrasonic Sensor Enablement-FY 2012 Status Report", INL/EXT-12-27233, Sept. 2012.**

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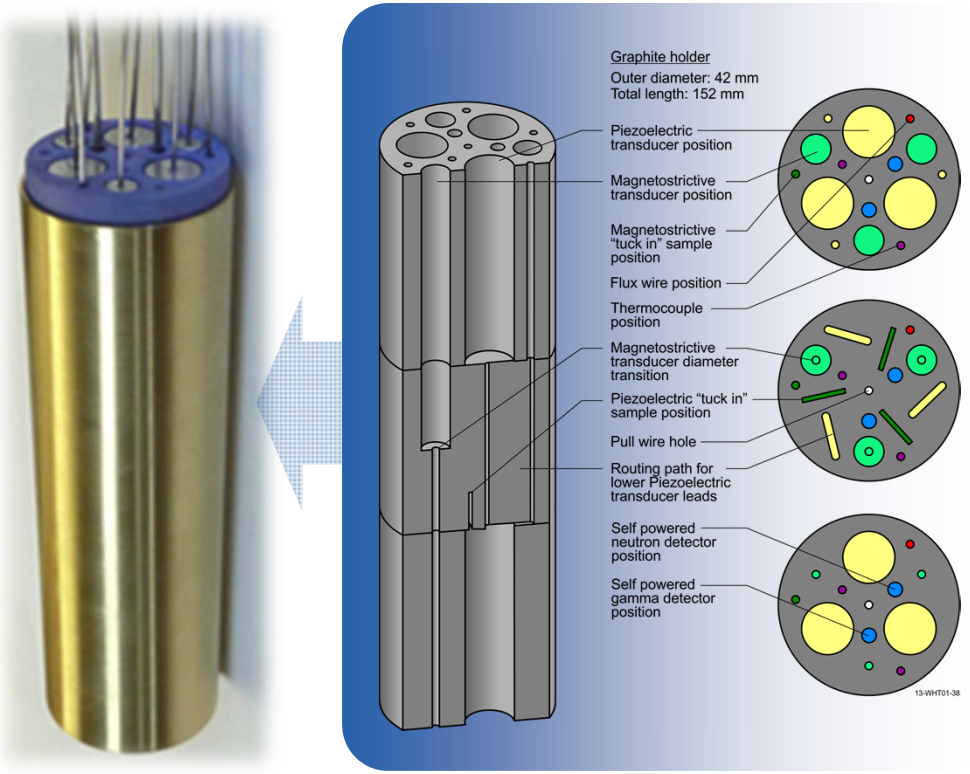
FY 2013 Activities

- **Ultrasonic Transducer Irradiation Survivability**
  - Capsule and transducer design and component selection
  - Test plan development
  - Complete transducer fabrication and transmit to MIT
- **Peer-reviewed publications**
  - ANIMMA 2013 Conference Paper
  - IEEE Journal Paper
- **"NEET In-Pile Ultrasonic Sensor Enablement-FY 2013 Status Report," INL/EXT-13-29144, to be issued in September 2013**.



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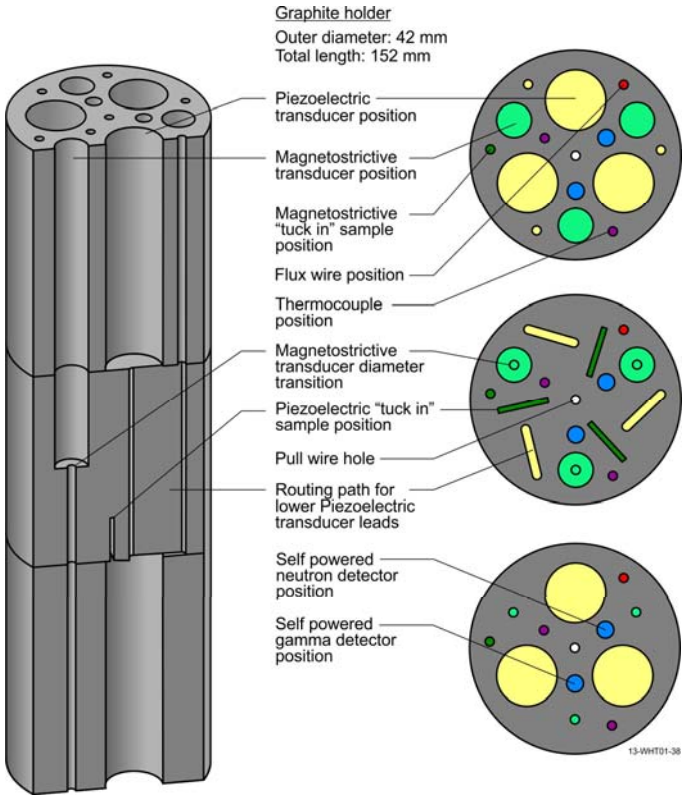
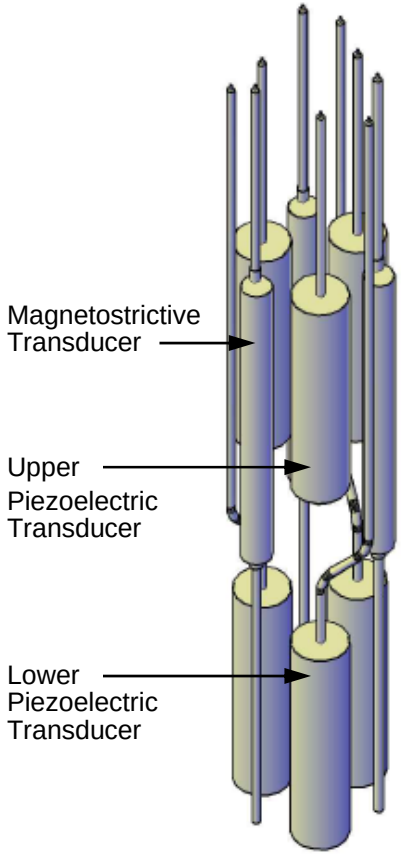
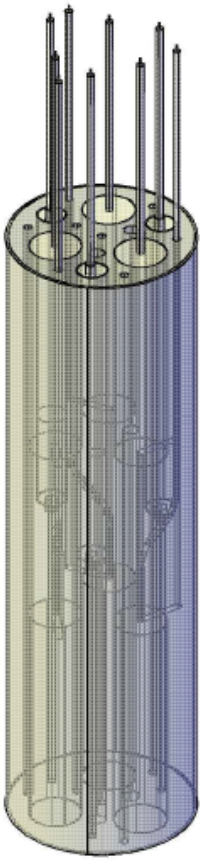
Accomplishments (FY-12,13)
Test Capsule Design



Graphite Holder



Transducer Positions



Assembly with Titanium Shell

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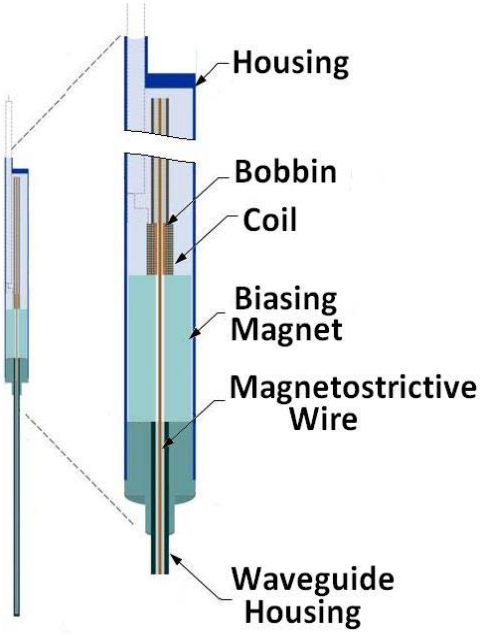
Accomplishments (FY-12,13) Transducer Design & Sensor Selection

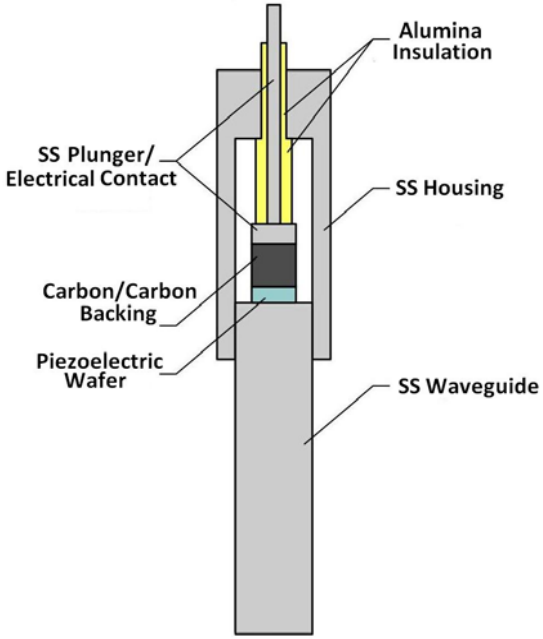
Magnetostrictive Materials

- Remendur
- Galfenol
- Arnokrome ("tuck in" only)



Piezoelectric Materials

- Aluminum Nitride
- Bismuth Titanate
- Zinc Oxide



Sensors

- 2 Type K Thermocouples
- 1 Vanadium Emitter Self Powered Neutron Detector
- 1 Platinum Emitter Self Powered Gamma Detector
- 4 Temperature Melt Wire Capsule
- Fast and Thermal Flux Wires

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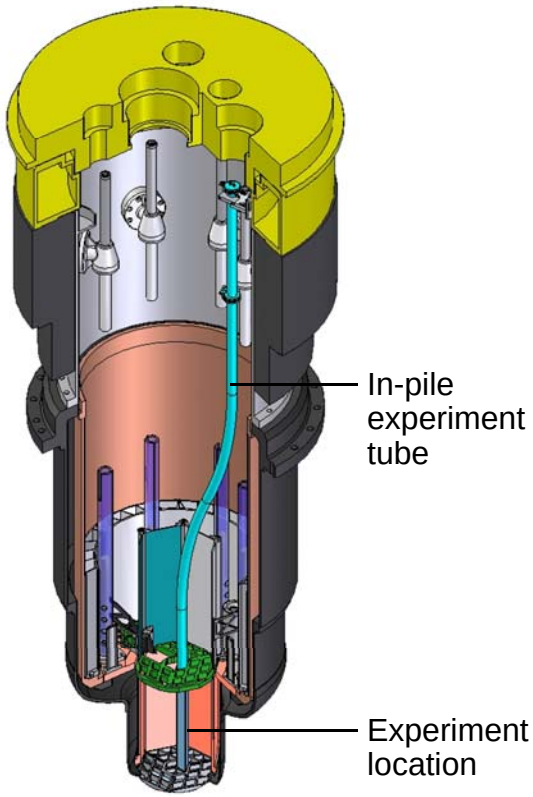
Accomplishments (FY-13)
Test Plan Development



MITR Test Location

Irradiation Test

- 18 Month Duration
- Total Fluence: >1x10^{21}n/cm^2 Fast
- Expected Temperature: ~400 ^{o}C

Laboratory Furnace Tests

- Long Duration Heating
- Thermal Cycling
- Maximum Operating Temperature

PIE

- Pulse-Echo
- Density
- Impedance
- Efficiency d_{33}
- Hysteresis
- Optical
- SEM

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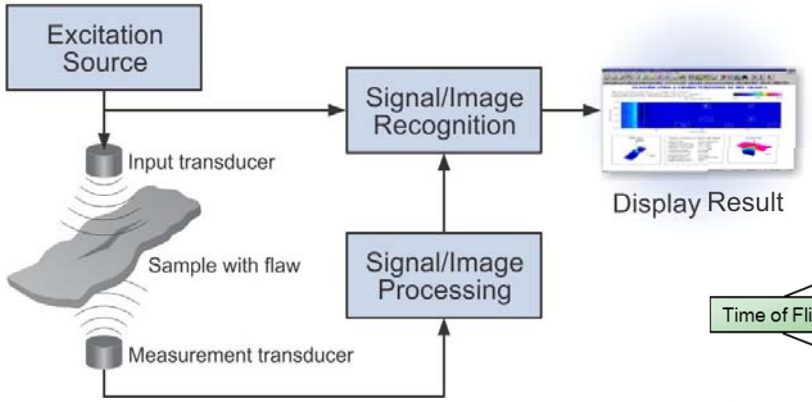
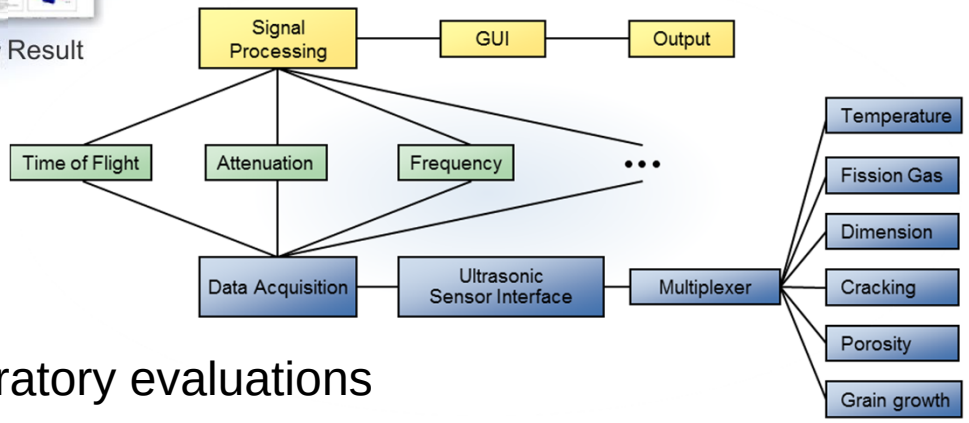
Planned Accomplishments





- **Transducer irradiation**
  - Complete PSU and INL laboratory evaluations
  - Validate data from ultrasonic transducer irradiation
  - Support PIE evaluations and data interpretation
- **Signal processing enhancement to be the focus of FY-14 work**
  - Development of algorithms for selected parameters
  - Benchmarking with representative/experimental data
- **Issue final program report.**

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Crosscutting Benefits

- **Project team selection and interactions with program leads ensure various DOE-NE programs (e.g., FCRD, ATR NSUF, ARC, SMR, NGNP, LWRS, TREAT Restart, etc.) customer requirements identified:**
  - Compact size
  - Multiple parameters monitored online (temperature profiling, fission gas evolution, etc.)
  - Radiation resistant
  - High temperature compatibility with appropriate materials
  - High accuracy
  - High resolution
  - Flexibility (variable applications, sensitivities, resolution, accuracies, etc.)
- **Continued interactions**
  - Distribute annual status reports and participate in program reviews to gain input and concurrence from cognizant experts in various DOE-NE programs.
- **Enables advanced sensor deployment and positions U.S. MTRs to become world-class leader in irradiation testing**
  - Enhanced capabilities for US research (DOE-NE, industry, regulators, NR, BES, etc.)
  - Attract foreign customers (industry, regulators, etc.)

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Crosscutting Benefits

FCRD

- Enables use of ultrasonic sensors in irradiation test rigs for high accuracy, high resolution measurement of temperature, gas composition and pressure, crack initiation and growth
- Sensors provide real-time data required for validating new multi-scale fuel models

ATR NSUF

- Enables use of ultrasonic sensors for measuring temperature, gas composition and pressure, elongation, crack initiation and growth in ATR NSUF irradiations
- Provides US MTR users unique new higher accuracy, higher resolution sensors

NGNP

- Enables use of high temperature ultrasonic sensors in irradiation test rigs and on-line monitoring of conditions in first plant
- Sensors provide real-time data to validate model predictions during irradiation and reactor operation

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Crosscutting Benefits (Cont.)

ARC

- Enables use of ultrasonic sensors in irradiation test rigs.
  - Flexibility of ultrasonic sensor design ideal for unusual geometries and harsh environments.
  - Sensors provide data for validating new multi-scale multi-physics models.
- On-line monitoring of SFR components
- Real-time monitoring of SFR plant conditions during first prototype and operating fleet
  - In-vessel ultrasonic flow meters
  - Core temperature profiling
  - Fuel performance
  - Material degradation

Advanced SMRs

- Flexibility of ultrasonic sensor design ideal for unusual geometries and harsh environments.
- On-line monitoring of SFR components and conditions

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Crosscutting Benefits (Cont.)

- **LWRS / Industry and Reactor Safety Programs**
  - Enables use of ultrasonic sensors in fuels and materials irradiation test rigs for high accuracy, high resolution measurement of temperature, gas composition and pressure, crack initiation and growth
    - Validation data for new fuels and materials models
    - Demonstrating the performance of accident tolerant fuels during long duration irradiations and transient irradiation tests.
  - Enables deployment of new enhanced accident tolerant sensors for the commercial fleet, such as water level within LWR reactor vessels and other large components (e.g., pressurizers, steam generators, etc.)

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Transition to Competitive Research

- **Enables advanced ultrasonic sensor deployment and positions U.S. MTRs to become world-class leader in irradiation**
  - Compact, robust sensors
  - Multiple parameter measurement (e.g., temperature, elongation, gas composition and pressure, crack initiation and growth, etc.)
  - Flexibility (variable applications, sensitivities, resolution, accuracies, etc.)
- **Anticipated hand-off to occur at end of MITR irradiation**
  - Programs (e.g., DOE-NE, NR, regulators, and industry) will implement appropriate transducer into sensor design and apply signal processing enhancements
  - Cross-cutting sensors applicable to multiple programs candidate for future NEET projects

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Conclusion

- **Leverages NEET funding to guide much needed irradiation test to quantify ultrasonic transducer materials survivability in high neutron flux MTRs for long duration irradiations**
- **Identifies signal processing requirements for in-pile measurement of various parameters with ultrasonic sensors**
- **Enables development of world-class, ultrasound-based instrumentation capability required for high flux US MTR irradiation tests needed by U.S. (DOE-NE, regulator, industry, and NR) and international programs**
  - Higher fidelity measurements than possible with current technologies
  - New measurements not currently possible in MTRs
  - Measurements in harsher conditions than currently possible.