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

Clean. Reliable. Nuclear.

Advanced Sensors and Instrumentation

Program Overview

October 23, 2019

Suibel Schuppner

Office of Nuclear Energy

U.S. Department of Energy

Advanced Sensors and Instrumentation (ASI) Program

Mission

Develop **advanced sensors and I&C** that address **critical technology gaps** for monitoring and controlling existing and advanced **reactors** and supporting **fuel cycle** development

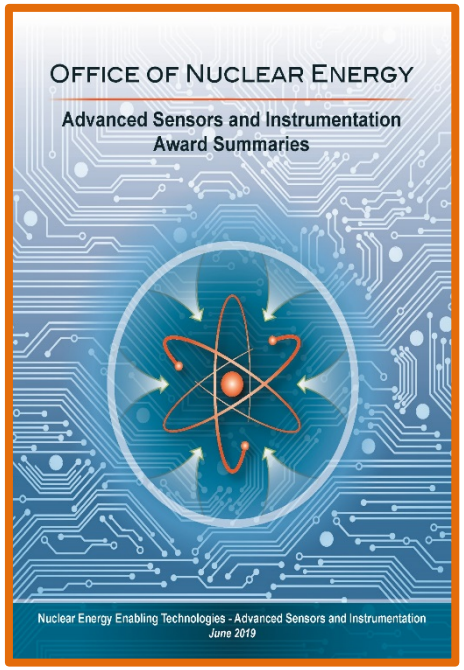
Vision

NEET ASI research results in advanced sensors and I&C technologies that are **qualified, validated, and ready to be adopted by the nuclear industry**

Advanced Sensors and Instrumentation (ASI) Program (Cont.)

Goals

- Support **DOE-NE R&D** programmatic needs
  - ➢ Fuel and material studies, integral tests
- Provide **new capabilities** for measurement, control, and operation
  - ➢ Sensors for harsh environments, advanced control capabilities, semi-autonomous and fault-tolerant operation, and predictive analytics
- Address R&D needs for **successful deployment**
  - ➢ Digital technology and instrumentation qualification

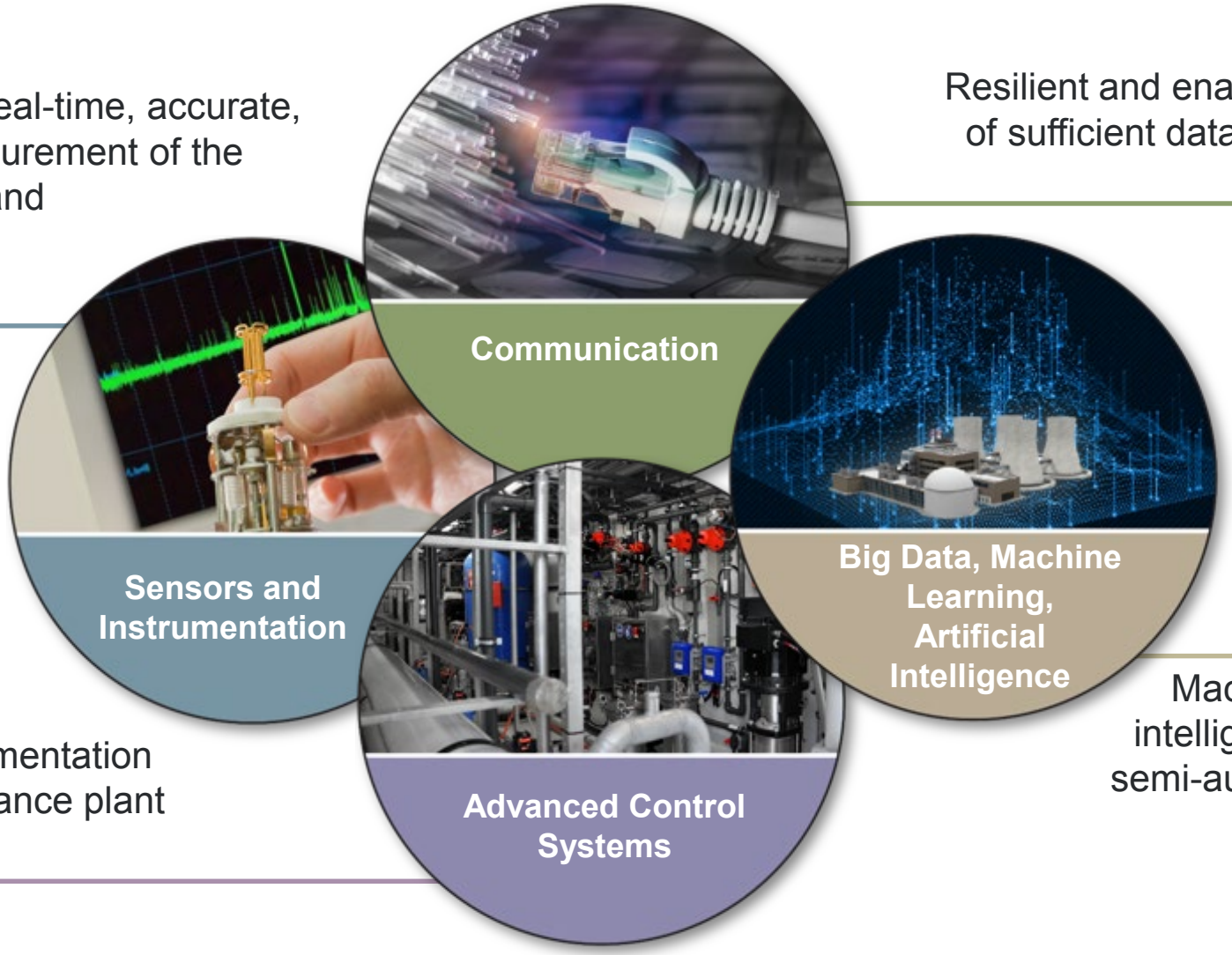


Advanced Sensors and Instrumentation (ASI) Webinar
Oct. 31, 2018 - Nov. 1, 2018

ASI Strategic Research and Development

Reliable, cost-effective, real-time, accurate, and high resolution measurement of the performance of existing and advanced reactors core and plant systems

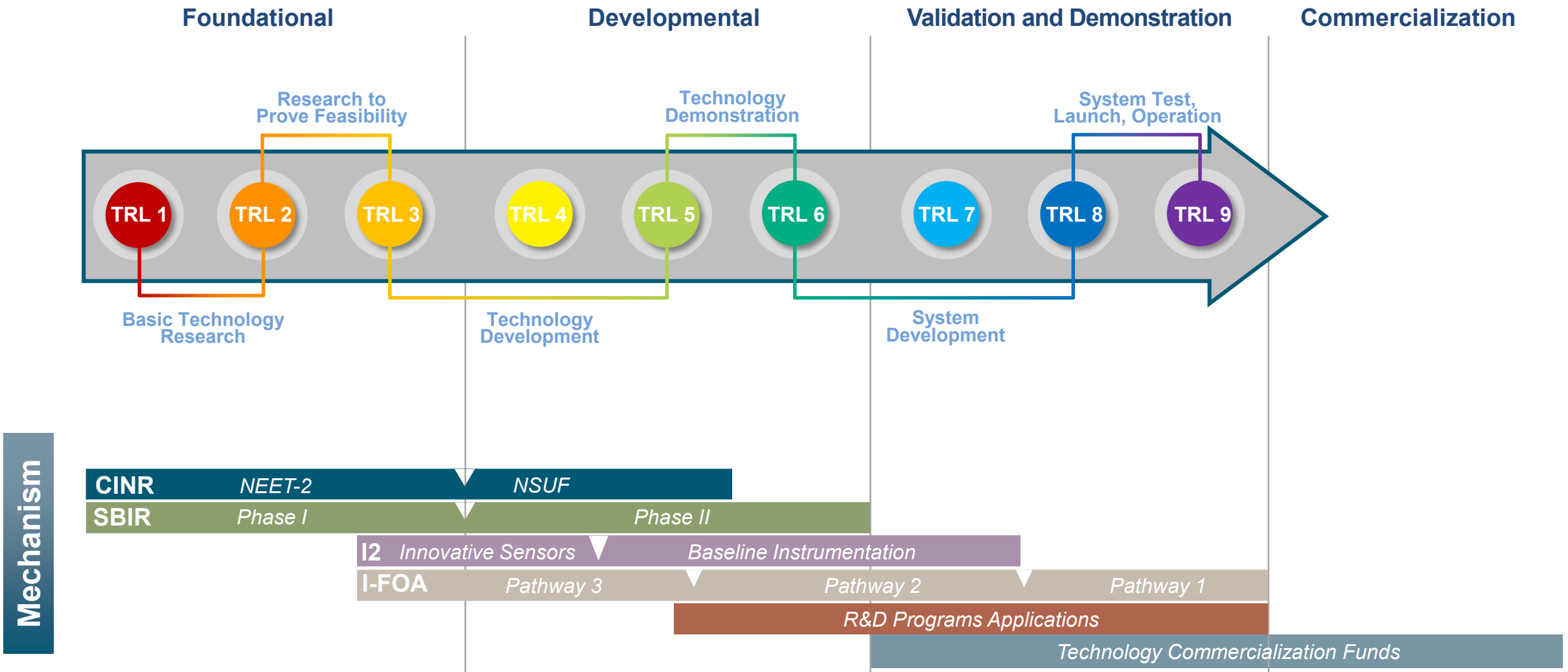
Resilient and enable real-time transmission of sufficient data for online monitoring and advanced data analytics



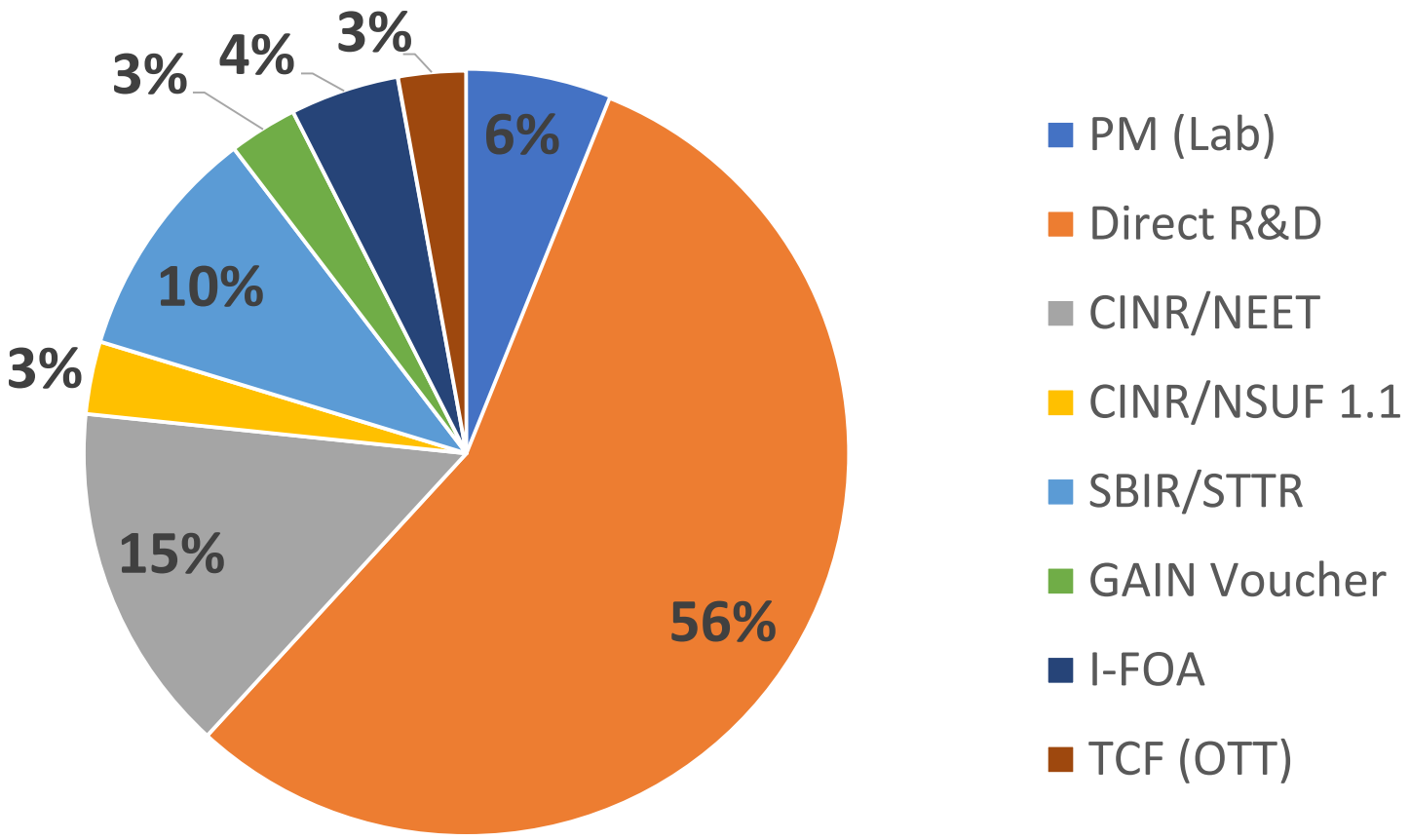
Enable near real-time control of plant or experimentation process variables to enhance plant thermal performance

Machine learning and artificial intelligence processes to enable semi-autonomous operations and maintenance by design

Metrics: ASI Research Progression



ASI Program Funding Breakdown



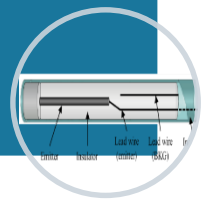
Percent based on active projects during FY19 ($21,746,330 total)

Direct Funding Research

Baseline Instrumentation

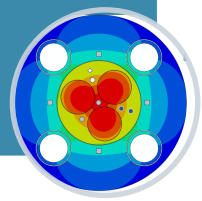
- Neutron and gamma detection
- Fast (Hf, Gd) and slow (Rd, Vd) response
- Established design/fabrication process at INL
- Performance demonstration in TREAT and AGR5/6/7

Self Power Detectors



- Continued HTIR demonstration and transition to commercialization (TCF fund, ASTM standards)
- Mo-Nb junction for high temperature applications (1600 C) and low drift under neutron irradiation
- Performance demonstration in AGR5/6/7 – highest temperature ever recorded in pile without drift (1482 C)

High Temperature Irradiation Resistant (HTIR) thermocouple

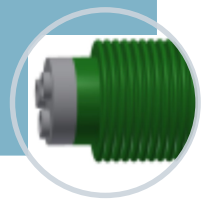


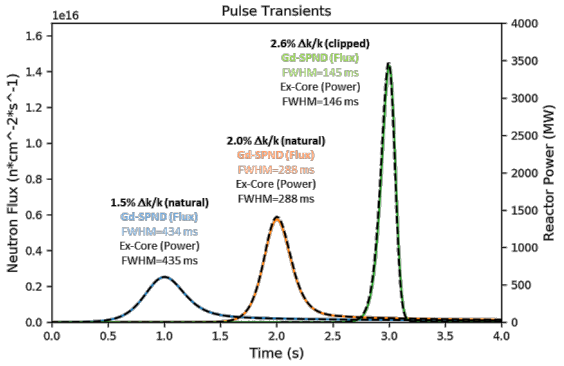
- Passive monitors are needed when real-time sensors are not practical or economical to install
- Specialized peak temperature and neutron fluence monitors and related analysis techniques for Post Irradiation Examination (PIE)
- Development focus on reliability and compatibility with standard material samples sizes (ie, 3 mm disc)

Passive temperature and flux monitors

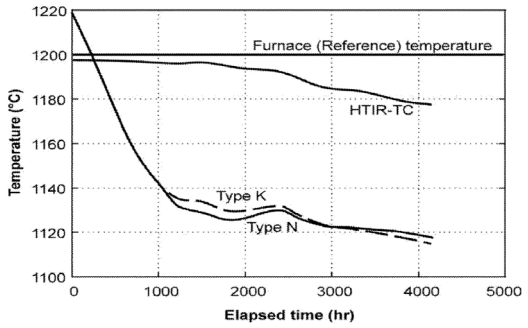
- Demonstrated performance under irradiation in test reactor environments
- The Halden Reactor Project (HRP) has optimized LVDT sensor technology and applications
- With the closure of HBWR the INL is working to recover HRP capabilities for DOE programs and the US nuclear industry

Linear Variable Differential Transformer (LVDT)

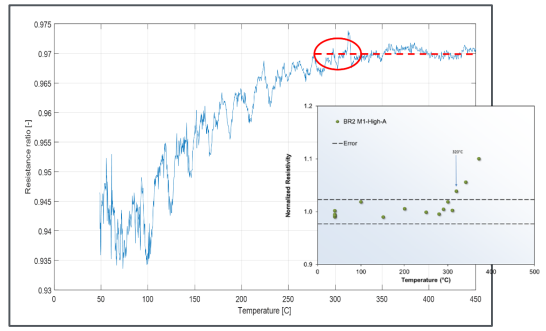




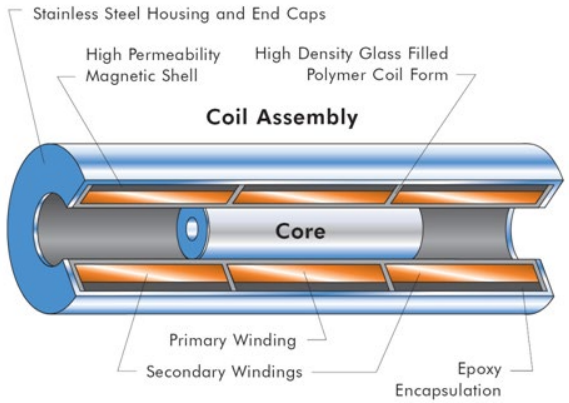
TREAT pulse transient with Gd- and Hf-SPNDs compared to an ex-core detector.



HTIR drift compared with type N, K



Continuous reading of SiC monitors in PIE after BR2 irradiation



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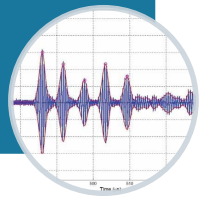
Direct Funding Research (Cont.)

Innovative Sensors

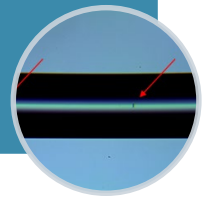
- Ultrasound based sensors enable distributed temperature measurements up to 3000ºC
- INL had demonstrated the reliability of magnetostrictive material transducers under irradiation
- Current research focuses on waveguide design optimization and unfolding signal response of distributed measurements

Ultrasonic Thermometers



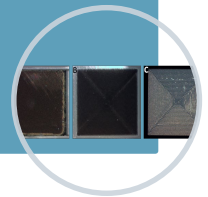
- Develop advanced sensor configuration and interrogation techniques to measure:
  - Fission gas pressure and composition
  - Flow induced vibration
  - Microreactor core performance
- Develop single mode sapphire fibers
- Develop modeling and simulation tools for fiber materials performance under irradiation

Optical fibers



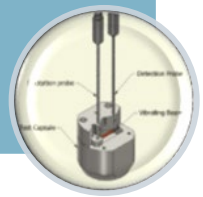
- Aerosol Jet Printing for the fabrication of nuclear instrumentation (ink development, process control)
- Combinatorial material science analysis for sensors design
- AM sensors: dosimeters strain gauges and thermal conductivity probes

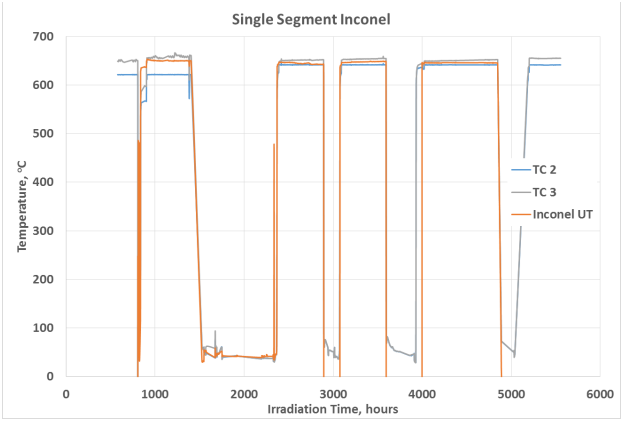
Advanced Manufactured Sensors

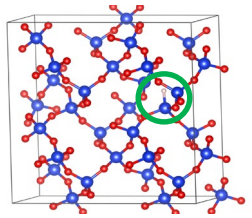


- In-pile monitoring of microstructure enables the study of material behavior that cannot be captured in PIE
- RUSL (Resonant Ultrasound Spectroscopy – Laser) instrument uses an optical fiber based technique monitoring microstructure evolution by measuring the elastic properties of a small cantilever beam
- On May 13, 2019, RUSL successfully tested a highly textured copper beam during TREAT irradiation

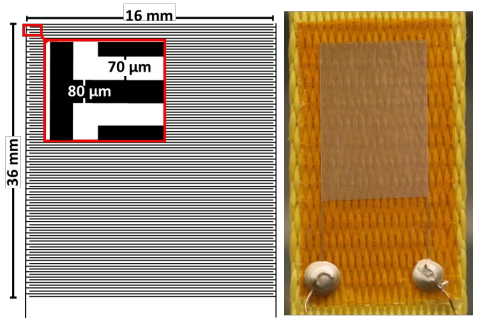
Microstructure Characterization



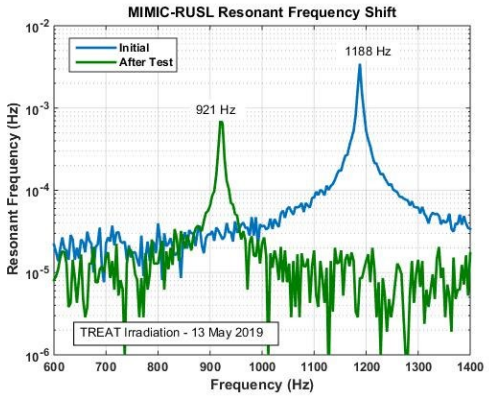




DRIFT experiment in TREAT with OF distributed T measurement



AJP strain gauge

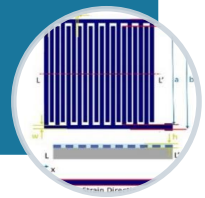


Direct Funding Research (Cont.)

Test Capabilities

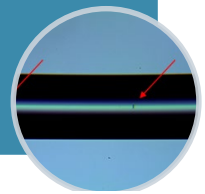
- Mechanical sensors provide measurements of the change in bulk mechanical properties of materials during irradiation
- Research to characterize sensors under prototypic loads, understand radiation resilience and enable reliable deployment
- Mechatronic assisted test platform for strain gauge test (Double Delta)

Mechanical sensors performance test



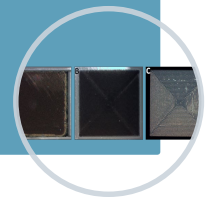
- Construct a flowing water autoclave loop for instrument qualification prior to deployment in irradiation test
- Part of DOE effort to recover capabilities after the closure of the Halden reactor (HBWR)
- **M2: Assemble and perform commissioning test of Flowing Autoclave facility**

Autoclave laboratory



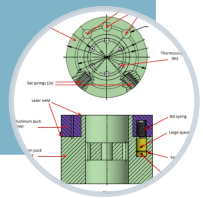
- MIMIC/MARCH is a modular system to perform low-cost, repeatable irradiations of instrumentation in the TREAT facility
- In addition to MIMIC-RUSL, it hosted a test to characterize the performance of neutron sensor (Gd-SPND, MPFD, AM dosimeters) to transient conditions (MIMIC-N)

MIMIC system



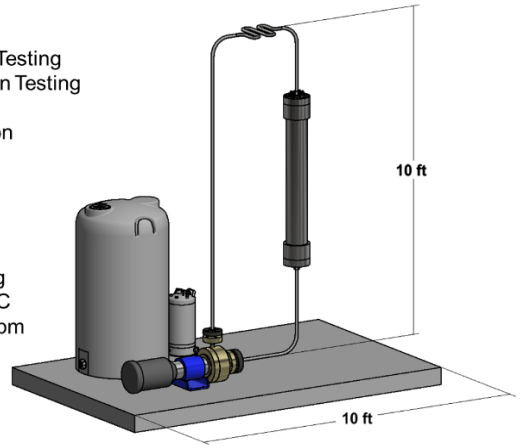
- DISECT is an irradiation test for the BR2 reactor at SCK, Belgium
- I2 supplied innovative temperature instrumentation: Fiber-optic temperature sensors (FO), and Ultrasonic thermometers (UT) to monitor the irradiations in real-time, and SiC temperature monitors for passive temperature monitoring.

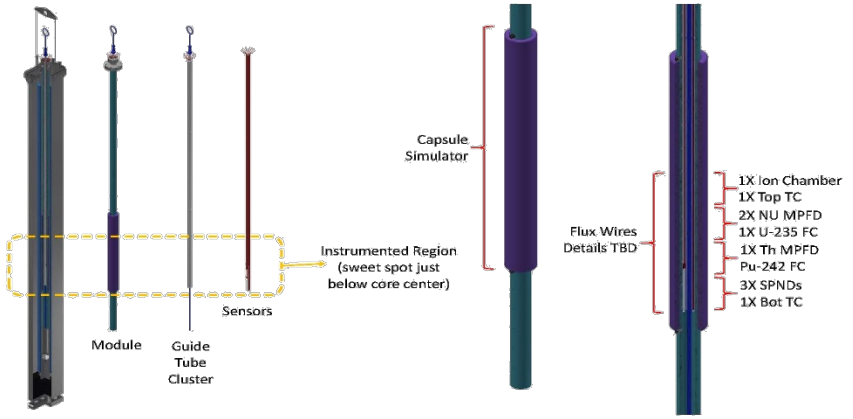
DISECT experiment

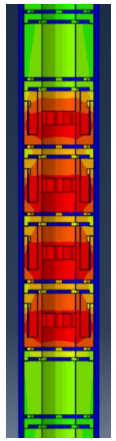


Capabilities
- Instrument/Sensor Testing
- Chemistry/Corrosion Testing
- Flow Testing
- Modeling Verification

Operating Conditions
- Coolant: Water
- Pressure: 2200 psig
- Temperature: 300 °C
- Flow Rate: 10-50 gpm







NE Funding Opportunity Announcements (FOAs)

- **Consolidated Innovative Nuclear Research (CINR)**
  - Nuclear Energy University Program (NEUP)
  - Integrated Research Projects (IRPs)
  - Nuclear Energy Enabling Technologies (NEET)
  - Nuclear Science User Facilities (NSUF)
- **Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)**
  - Advanced Technologies for Nuclear Energy
  - Phase I Release 2
- **U.S. Industry Opportunities for Advanced Nuclear Technology Development (DE-FOA-0001817)**
- **Gateway for Accelerated Innovation in Nuclear (GAIN) Vouchers**

GAIN
Gateway for Accelerated Innovation in Nuclear

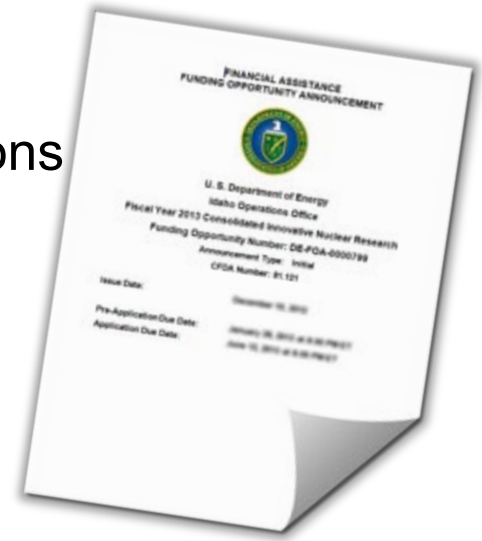
https://gain.inl.gov

FY 2020 Consolidated Innovative Nuclear Research (CINR) Funding Opportunity Announcement (FOA)

- **University-led R&D** [Nuclear Energy University Programs (NEUP)]
  - Program and Mission Supporting
- **Industry-, University-, or National Laboratory-led** R&D [Nuclear Energy Enabling Technologies (NEET) Program]
  - **Advanced Sensors and Instrumentation**
  - Advanced Methods for Manufacturing
  - At least 20% cost share for industry leads
- **University-led, Program Directed Integrated Research Projects [NEUP]**
  - Program Directed work

- **CINR Due dates:**
  - September 4, 2019: NSUF Letter of Intent
  - September 24, 2019: R&D/NSUF Pre-Applications
  - November 21, 2019: NSUF Preliminary Statement of Work
  - January 23, 2020: NSUF Final Statement of Work
  - February 11, 2020: Full R&D Applications
  - February 11, 2020: IRP Applications

www.neup.gov



NEET-ASI Current CINR Awards

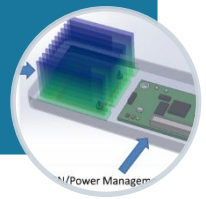
FY	Project Title	Principal Investigator
2016	Transmission of Information by Acoustic Communication along Metal Pathways in Nuclear Facilities	Richard Vilim, Argonne National Laboratory
2016	Wireless Reactor Power Distribution Measurement System Utilizing an In-Core Radiation and Temperature Tolerant Wireless Transmitter and a Gamma-Harvesting Power Supply	Jorge Carvajal, Westinghouse Electric Company
2016	Self-powered Wireless Through-wall Data Communication for Nuclear Environments	Lei Zuo, Virginia Tech
2017	Integrated silicon/chalcogenide glass hybrid plasmonic sensor for monitoring of temperature in nuclear facilities	Maria Mitkova, Boise State University
2017	High temperature embedded/integrated sensors (HiTEIS) for remote monitoring of reactor and fuel cycle systems	Xiaoning Jiang, North Carolina State University
2017	3-D Chemo-Mechanical Degradation State Monitoring, Diagnostics and Prognostics of Corrosion Processes in Nuclear Power Plant Secondary Piping Structures	Douglas Adams, Vanderbilt University
2017	Versatile Acoustic and Optical Sensing Platforms for Passive Structural System Monitoring	Gary Pickrell, Virginia Polytechnic Institute and State University
2018	Process-Constrained Data Analytics for Sensor Assignment and Calibration	Richard Vilim, Argonne National Laboratory
2018	Analytics-at-scale of Sensor Data for Digital Monitoring in Nuclear Plants	Vivek Agarwal – Idaho National Laboratory
2018	Development of optical fiber- based gamma thermometer and its demonstration in a University Research Reactor using statistical data analytic methods to infer power distributions from gamma thermometer response	Thomas Blue, The Ohio State
2019	Design of Risk Informed Autonomous Operation for Advanced Reactor	Michael Golay, Massachusetts Institute of Technology
2019	Cost-Benefit Analyses through Integrated Online Monitoring and Diagnostics	David Grabaskas, Argonne National Laboratory
2019	Acousto-optic Smart Multimodal Sensors for Advanced Reactor Monitoring and Control	Michael Larche, Pacific Northwest National Laboratory
2019	Context-Aware Safety Information Display for Nuclear Field Worker	Pingbo Tang, Arizona State University
2019	Advanced Online Monitoring and Diagnostic Technologies for Nuclear Plant Management Operation, and Maintenance	Daniel Cole, University of Pittsburgh

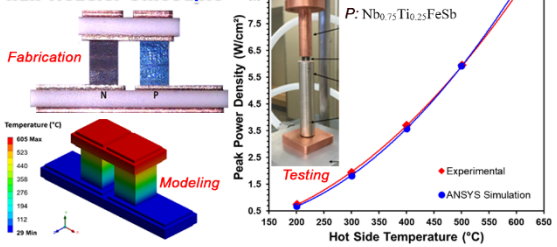
NEET-ASI CINR Examples

Competitive Awards: NEET - ASI

- Develop high-efficiency and reliable thermoelectric generators to self-power wireless sensor nodes
- Designed and fabricated a robust nanostructured bulk TEG with ultrahigh power density of 8.5 W/cm^2.
- Demonstrated a wireless sensor network powered by the TEG.

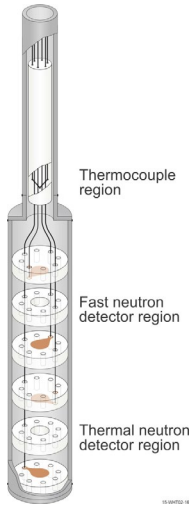
Nanostructured Bulk Thermoelectric Generator for Power Harvesting for Self-Powered Sensor Network

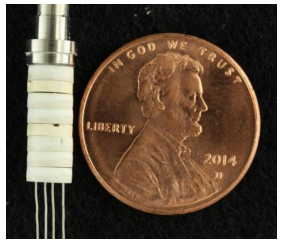




- Develop and test high temperature capable Micro-Pocket Fission Detectors
- Measured thermal neutron flux, fast neutron flux and temperature within a single package
- Irradiation experiment was performed at ATR, TREAT, University test reactors, and CEA

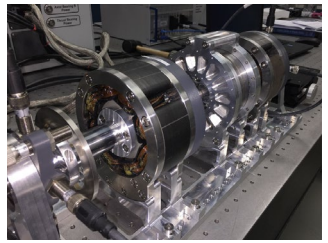
Enhanced Micro-Pocket Fission Detector for High Temperature Reactors

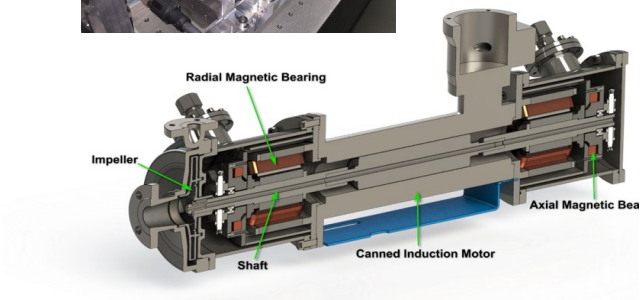




- Demonstrate performance gains possible using embedded I&C in high temperature, radiation, pressure, and vibration conditions
- Demonstrate a magnetically suspended canned-rotor motor using functional embedding
- The technology would make nuclear power more reliable, efficient, and less costly

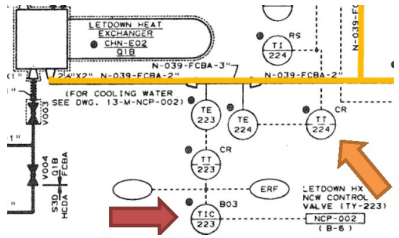
Embedded Instrumentation and Controls for Extreme Environments





- A prototypic computerized operator support system (COSS) was developed for assisting operators in monitoring plant conditions, in making timely and informed decisions
- The COSS underwent a first evaluation workshop conducted with licensed operators on fault in the Chemical and Volume Control System

Operator Support Technologies for Fault Tolerance and Resilience



Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STT) : Advanced Technologies for Nuclear Energy

- **Competitive awards for small businesses only**
- **Winners keep the rights to any technology developed and are encouraged to commercialize the technology**
- **Funded by federal R&D budgets set aside**

<u>NE funds SBIR and STTR projects</u>

- **Office of Nuclear Energy Section**

<u>Phase I Release 2</u>
- **Topics Issued: November 12, 2019**
- **Webinar: November 18, 2019**
- **FOA Issued: December 16, 2019**
- **LOI Due: January 27, 2020**
- **Application Due: February 24, 2020**

<u>Phase I Release 2</u> (only Phase I awardees are eligible to apply)
- **FOA Issued: March 2, 2020**
- **LOI Due: April 1, 2020**
- **Application Due: April 21, 2020**

www.science.energy.gov/sbir

SBIR Current Awards

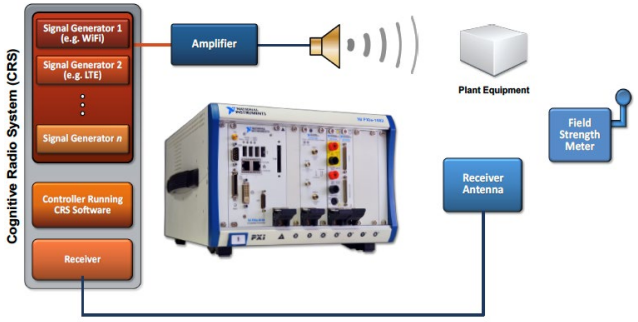
FY	Project Title	Principal Investigator
	PHASE II	
2016	High Temperature Operable, Harsh Environment Tolerant Flow Sensors For Nuclear Reactor Applications	Jon Lubbers, Sporian Microsystems, Inc
2017	A robust wireless communication system for harsh environment including nuclear facilities	Richard Twogood, Dirac Solutions Inc
2018	Distributed Antenna System for Wireless Data Communication in Nuclear Power Plants	Chad Kiger, Analysis & Measurement Serv Corp
2018	Fiber-Optic Sensor for Simultaneous Measurement of Temperature and Pressure	Derek Rountree, Luna Innovations Inc
2019	Metamaterial Void Sensor for Fast Transient Testing	Mark Roberson, Goldfinch Sensor Technologies and Analytics LLC
2019	Health Monitoring of Digital I&C Systems using Online Electromagnetic Measurements	Chad Kiger, Analysis & Measurement Serv Corp
2019	Fault Detection of Digital Instrumentation and Control Systems using Integrated Electromagnetic Compatibility and Automated Functional Testing	Greg Morton, Analysis & Measurement Serv Corp
	PHASE I	
2019	Sapphire Single Mode Fiber Development Towards High Temperature Radiation Resilient Sensors	Derek Rountree, Luna Innovations Inc
2019	Noncontact Flow Rate Sensor Using Laser Ultrasonics	Marvin Klein, Intelligent Optical Systems Inc
2019	Radiation Hardened Vision System for Nuclear Energy, Visual Inspection, and Accountability	Alan Sugg, Vega Wave Systems
2019	Video Camera for Harsh Environments in Nuclear	Esen Salcin, Alphacore Inc

SBIR Projects Examples

Competitive Awards: SBIR - ASI

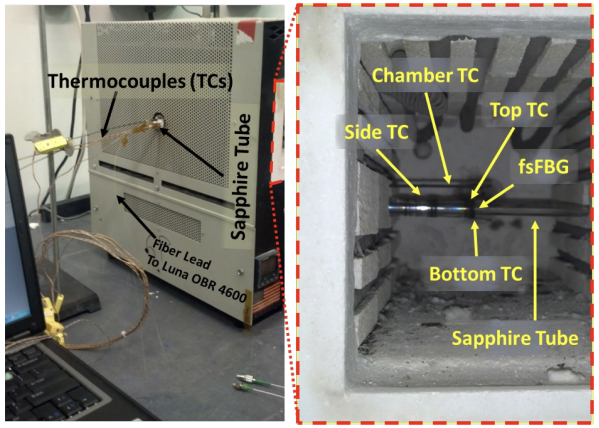
- Develop a system that establishes objective exclusive distances for safe and reliable operation of wireless devices in nuclear facilities
- Cognitive radio system is a light-weighted portable unit that can be used in plant for radiated immunity and wireless co-existence
- Electromagnetic waves transmitted and received don't interfere with other wireless devices

Assessing the EMI/RFI Risks of Wireless Devices Using A Cognitive Radio System



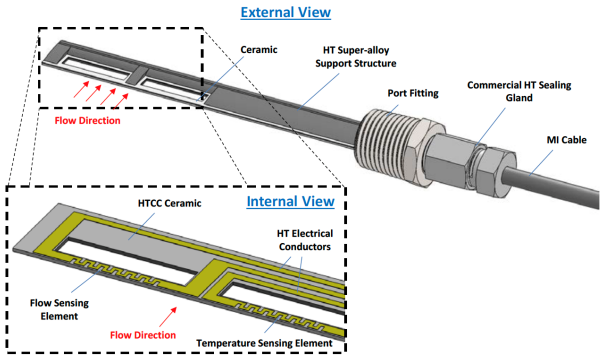
- Desire sensors that reduce containment vessel feedthrough count
- Combine fiber optic sensors to measure multiple properties
- Temperature and pressure measurements are achieved by combining Fiber Bragg Gratings on the same fiber
- The manufactured FBGs are radiation hardened sensors

Fiber–Optic Sensor for Simultaneous Measurement of Temperature and Pressure



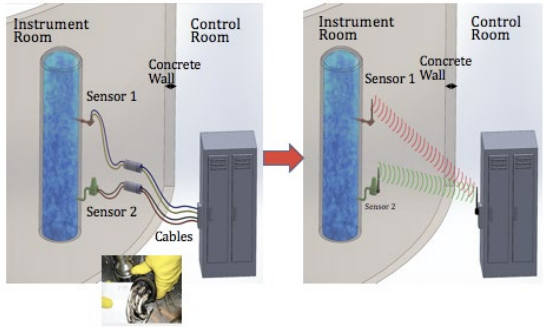
- Technical approach is based on established anemometry methods
- Combines liquid and gas flow sensors
- Able to operate in harsh environmental conditions
- The solution focuses on material, packaging, and testing to include borated water, irradiation effects, media isolation (i.e., high pressure sealing)

Coolant Flow Sensor for Small Modular Reactors



- Develop and evaluate a secure and reliable wireless sensor communication to address unique challenges of radio frequency communication in nuclear facilities
- Develop an ultra-wideband (UWB) technology to address concerns associated with traditional wireless technologies in nuclear reactors

A Robust Wireless Communication System for Harsh Environments Including Nuclear Facilities



Source: IAEA

U.S. Industry Opportunities for Advanced Nuclear Technology Development (DE-FOA-0001817)

- **The U.S. Department of Energy (DOE) is soliciting proposals for cost-shared projects to develop innovative industry-driven reactor designs and technologies to advance nuclear power in America.**
- **This funding opportunity is open for a five-year period.**
- **Applications will be accepted on a year-round basis with selections announced every quarter.**
- **Open to U.S. companies with the expectation that resulting products will be manufactured in U.S. after reaching commercialized state.**
- **Industry cost share will be between 20-50%, depending on the nature of the proposal**

Pathway	DOE Funding Range	Cost Share	Duration
First-of-a-Kind (FOAK) Nuclear Demonstration Readiness Projects	$10M-$40M	50/50	3 years
Advanced Reactor Development Projects	$500K-$10M	80/20	2 years
Regulatory Assistance Grants	$50K-$500K	80/20 or 50/50	1 year

<u>Gateway for Accelerated Innovation in Nuclear (GAIN) Vouchers</u>

- **Provide funds to assist industry applicants seeking access to world class expertise and capabilities available across the U.S. DOE Complex**

https://gain.inl.gov

Industry I&C Current Awards

FY	Voucher Title	Recipient
2017	Radiation Aging of Nuclear Power Plant Components	Analysis & Measurement Serv Corp Knoxville, TN
2017	Human Factors Engineering for the Move to Digital Control Systems – Improved Strategies for Operations	GSE Systems Inc. Sykesville, MD
2018	Advancement of Instrumentation to Monitor IMSR® Core Temperature and Power Level	Terrestrial Energy USA New York, NY
2018	Electroanalytical Sensors for Liquid Fueled Fluoride Molten Salt Reactor	ThorCon, Stevenson, WA
2019	Testing of Instrumentation and Control Sensors and Cables for Small Modular Reactors	Analysis & Measurement Serv Corp Knoxville, TN

FY	I-FOA Title	Recipient
2018	Resolving the Regulatory Issues with Implementation of Online Monitoring Technologies to Extend the Calibration Intervals of Process Instruments in Nuclear Power Plants	Analysis & Measurement Serv Corp Knoxville, TN
2019	Passive Radio Frequency Tags and Sensors for Process Monitoring in Advanced Reactors	Dirac Solutions Inc. Pleasanton, CA
2019	Application of Machine Learning for Enhanced Diagnostic and Prognostic Capabilities of Nuclear Power Plant Assets	Blue Wave Capital and Consulting, DBA Blue Wave AI Labs, Celebration, FL

Future ASI Initiatives

- Continue to engage stakeholders to better define program requirements (technical gaps and priorities identification)
  - Targeted Workshops with Industry
  - Close interaction with current DOE initiatives
  - Targeted focused scopes for solicitations
  - Communication with the NRC
  - Participation in Standards Committees

- Develop Strategic Plan to achieve program vision
  - Annual Goals
  - Deliverables
  - Timeline
  - Budget

https://www.energy.gov/ne/advanced-sensors-and-instrumentation-asi-program-documents-resources

Sensor Technologies for Advanced Reactors Workshop

- GAIN, EPRI, and NEI workshop to exchange of 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

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

GAIN
Gateway for Accelerated Innovation in Nuclear

Nuclear Energy Sensors Database

Purpose: Collect, store, and maintain nuclear power plant sensor technology information for nuclear energy applications

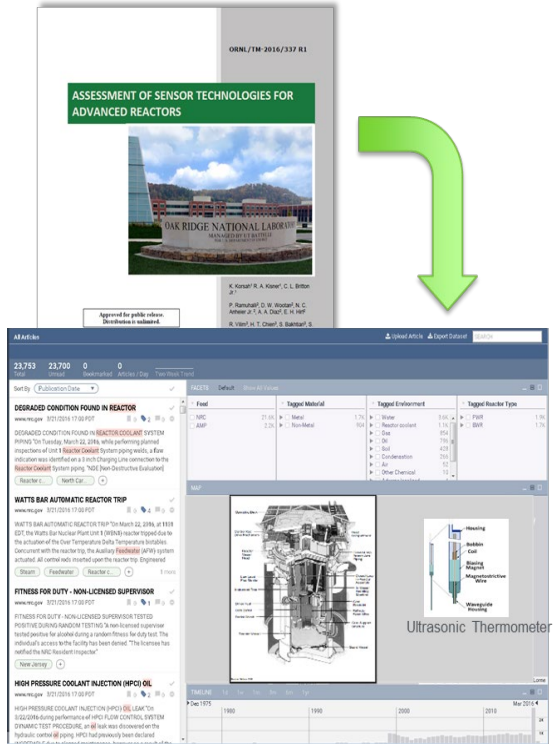
Objective: Provide the nuclear industry with a mechanisms to browse and search sensor data

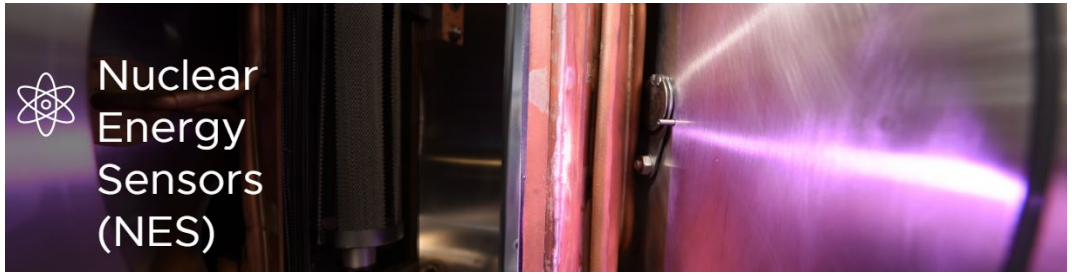
Initial information: ORNL/TM-2016 “Assessment of Sensor Technologies for Advanced Reactors”.

Including:

- Nuclear energy sensors
- Sensors use cases
- Sensors needs and gaps

Goal: Expand sensors dataset based on input from the user community





Summary

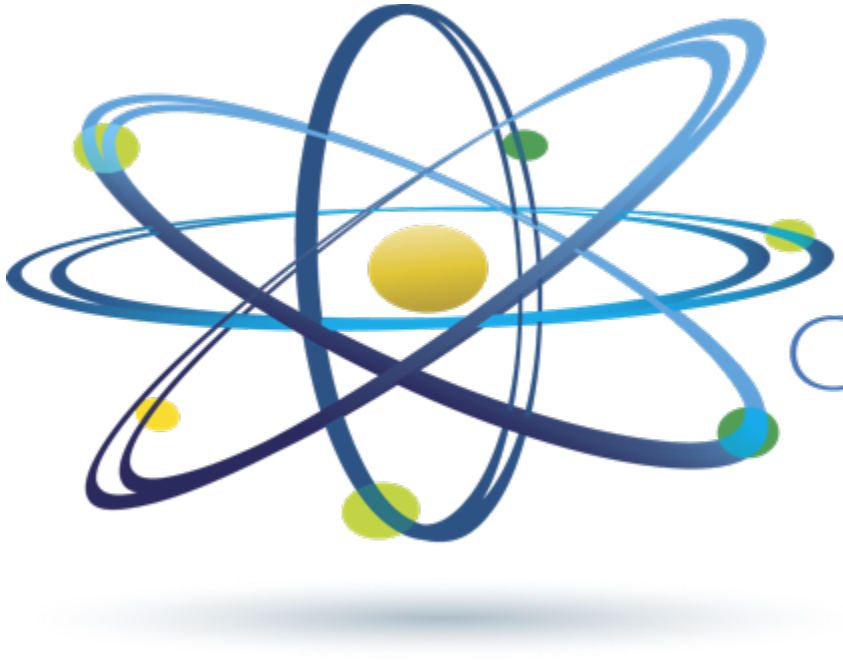
- Improvements and advancements in ASI technologies will
  - enable advances in nuclear reactor and fuel cycle system development
  - enhance economic competitiveness for nuclear power plants, and
  - promote a high level of nuclear safety

- NEET-ASI research produces concepts, techniques, capabilities, and equipment that are or can be demonstrated in simulated or laboratory test bed environments representative of nuclear plant systems or fuel cycle systems

- Innovative and crosscutting research is funded through competitive, peer-reviewed, solicitations

I&C technologies are a vital key to enabling the expansion of clean, safe, and economical nuclear power

Thank You!



Clean. **Reliable. Nuclear.**