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Nuclear Energy Enabling Technologies (NEET)

Advanced Sensors and Instrumentation (ASI)

Bruce P. Hallbert

Office of Nuclear Energy

Instrumentation and Controls Meeting

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Nuclear Energy Enabling Technologies: Advanced Sensors and Instrumentation

Vision

Develop advanced sensors and instrumentation technologies that address critical technology gaps for monitoring and controlling advanced reactors and fuel cycle facilities

Goal

To provide crosscutting research that:

- **Contributes to the success of the DOE-NE R&D programs**
- **Supports common I&C technology development needs**
- **Overcomes current and future I&C barriers to nuclear energy system deployments**

A new model of I&C innovative RD&D to overcome nuclear power's impediments to new I&C technology usage

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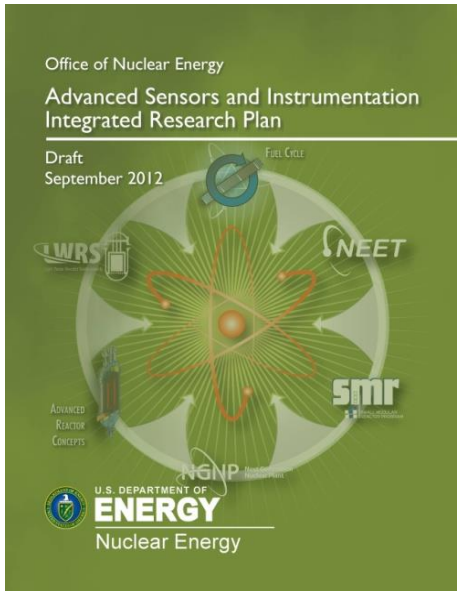
Integrated Capabilities

- **Create needed ASI technologies essential to realize DOE-NE mission goals**
  - Develop enabling capabilities that address common ASI gaps
  - Yield game-changing results for specific nuclear technologies
  - Address issues beyond the scope of individual R&D programs
  - Coordinate ASI research among programs to avoid duplication and leverage investment to benefit multiple programs.



- **Four Strategic areas:**
  - Advanced Sensors
  - Digital Monitoring and Control
  - Nuclear Plant Communication
  - Advanced Concepts of Operation

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FY-12 Research Projects
Advanced Sensors

Micro-Pocket Fission Detectors

Develop sensor for in-pile flux detection instrumentation for fuel and material testing

Project will provide:

- Real time detection in single compact detector
- Enhanced measurement capabilities for irradiation testing (compact, long detector lifetime, variable sensitivity)
- Capable of measuring thermal, fast flux, and temperature simultaneously

High Temperature Fission Chambers

Produce and characterize a working in-core prototype fission chamber.

Project will provide:

- Identification of materials suitable for harsh environments
- Radiation tests to understand heat, chemical, and radiation damage effects
- In-core flux measurements

Ultrasonic Transducers

Potential to measure range of parameters, geometry changes, temperature, crack initiation, growth, gas pressure, composition, and microstructural changes, under harsh irradiation test conditions.

Project will provide:

- Characterize potential identifying significant reductions in irradiation capsule size if piezoelectric transducers be deployed in-pile
- Develop need for ultrasonic measurement techniques to enhanced signal processing

Recalibration Methodology for Transmitters and Instrumentation

Enable on-line sensor calibration monitoring and extended recalibration intervals

Project will provide:

- Evaluation of sensor degradation and failure modes
- Set-point evaluation
- Virtual sensor to replace identified faulty sensors

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FY-12 Research Projects
Digital Monitoring and Control

Digital Technology Qualification

Identify key issues that compromise the determination of digital technology qualification for nuclear power applications.

Project will focus on:

- Mitigation of digital common-cause failure vulnerability
- Digital alternatives to analog measurement and actuation equipment

Sensor Degradation Control System

New approaches for mitigating the effect of power plant sensor degradation and measurement uncertainty.

- At the Individual Sensor Level – Model the degradation processes to reduce uncertainty estimate for the value of the process variable sensed
- At the Sensor Network Level - Integrate physics and measurement data to further reduce uncertainty estimate

Embedded Instrumentation and Controls

Develop and demonstrate sensors and controls that operate as embedded parts of a high-temperature, magnetic bearing, canned rotor pump.

Project will focus on:

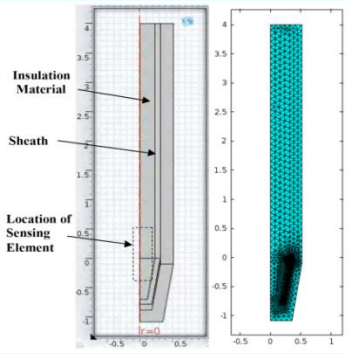
- Pump incorporation
  - Coupled multi-axis position
  - High temperature tolerant position sensors
  - Fault tolerant computing and controls
  - High temperature magnetic actuators and wiring

Design for Fault Tolerance

Advanced equipment fault-detection and identification algorithms provide plant operator tools for informed response to equipment faults.

Project will focus on:

- Integration of fault detection and identification software and control algorithms simulation
- Elements of component failure or degradation, identification of failure or degradation, automated control system response



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FY-12 Research Projects
Nuclear Plant Communication

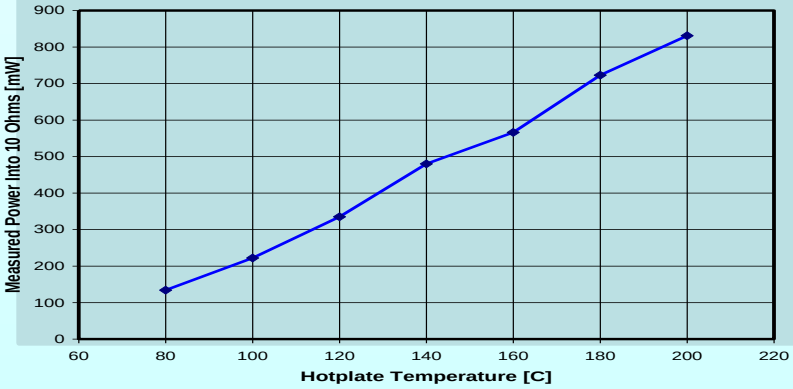
Power Harvesting Technologies

Develop, demonstrate an advanced multi-functional, power-scavenging system for nuclear power plants.

System will enable:

- Monitoring during both normal and post-accident operational scenarios
- Cost effective sensor deployment
- Increased redundancy, security, and safety of current and future reactors

Measured thermopile output power into a 10-ohm load using carbon foam conductors with thermal grease



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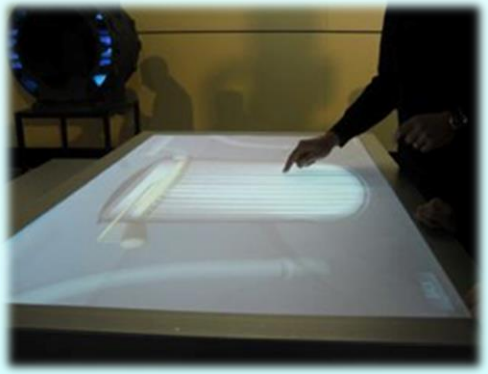
FY-12 Research Projects
Advanced Concepts of Operation

Advanced Human-System Interfaces (HSI)

Provide error-tolerant and resilient operation in control rooms and to enable a superior degree of operator task performance.

Project will focus on:

- Resilient control systems that limit the effect of human error while also reducing workload
- Allocate functions to humans and systems to present plant process and state information to the operator for efficient and safe operations.



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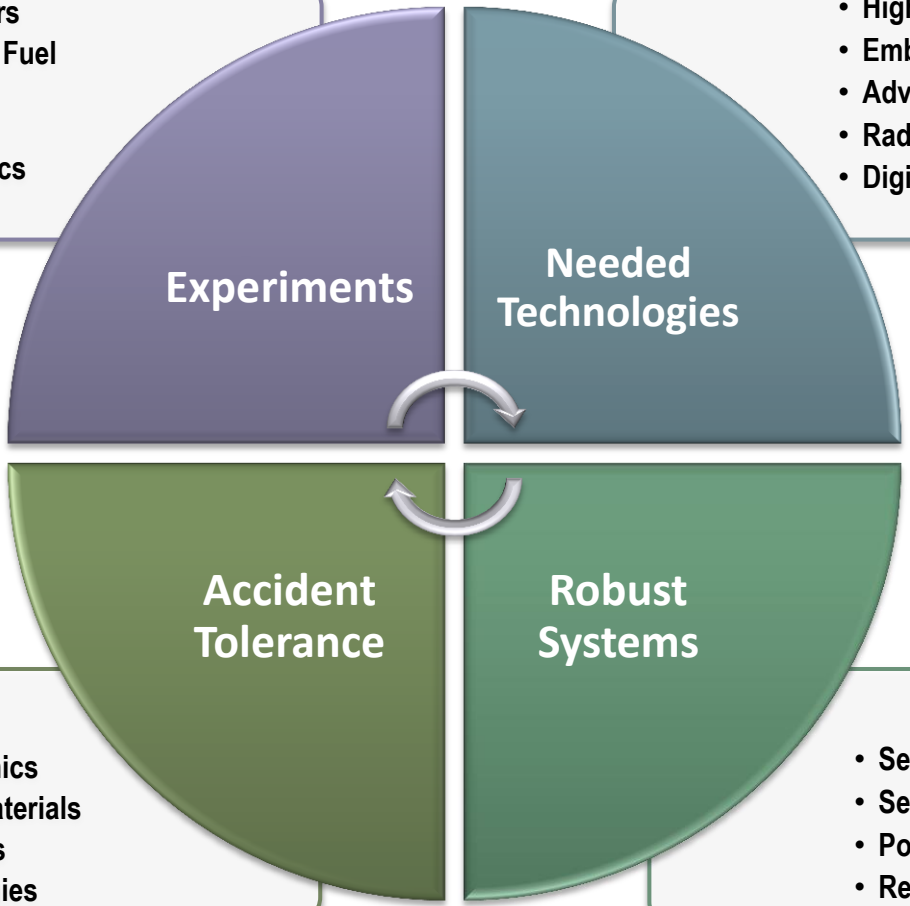
Supports Programmatic Goals & Develops Needed Capabilities

- Micro Pocket Fission Detectors
- Ultrasonic Sensors for In-pile Fuel Irradiation
- High Temperature Materials
- Radiation Hardened Electronics

- High Temperature Fission Chambers
- Embedded Instrumentation & Controls
- Advanced HSI Technologies
- Radiation Hardened Electronics
- Digital Technology Qualification



- Radiation Hardened Electronics
- High Temperature Sensor Materials
- Sensor Degradation Controls
- Power Harvesting Technologies

- Self Calibrating Sensors
- Sensor Degradation Controls
- Power Harvesting Technologies
- Resilient Controls

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FY-13 NEUP Awards

Title	Institution	Estimated Funding	Award Description
Radiation Hardened Electronics Destined for Severe Nuclear Reactor Environments	Arizona State University	$399,674	Researchers will develop radiation hard by design (RHBD) electronics using commercially available technology employing commercial off-the-shelf (COTS) devices and present generation circuit fabrication techniques. This project will increase the radiation resilience of more sensitive electronics such that a robot could be employed for post-accident monitoring and sensing purposes as well as for long-term inspection and decontamination missions.
Radiation Hardened Circuitry Using Mask-Programmable Analog Arrays	Oak Ridge National Laboratory	$400,000	Researchers will develop and demonstrate a general-purpose data acquisition system built from commercial or near-commercial radiation-hard analog arrays and digital arrays to be the building blocks of a family of future fieldable radiation-hard systems. The result will be a prototype rad-hard data acquisition system constructed and tested to demonstrate functionality and rad-hardness of the identified commercially available technology, as applied to a nuclear reactor environment.
A Method for Quantifying the Dependability Attributes of Software-Based Safety Critical Instrumentation and Control Systems in Nuclear Power Plants	Ohio State University	$399,990	Researchers will address the lack of systematic science-based methods for quantifying the dependability attributes in software-based instrumentation and control systems in safety critical application. This research will lead to the development of hybrid causal maps, an advanced representation of knowledge, as well as to a more robust elicitation of causal maps which further enhance the science of elicitation.

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FY-14 Awards

Advanced Sensors & Instrumentation			
Operator Support Technologies for Fault Tolerance and Resilience	Argonne National Laboratory	$995,000	Researchers will develop control systems technologies for nuclear plants that significantly enhance the response to time-critical component faults, resulting in fewer nuclear safety challenges and higher plant capacity factors. This technology retains an operator's judicious use of control strategies to minimize the impact to the plant, while greatly improving human performance.
Nanostructured Bulk Thermoelectric Generator for Efficient Power Harvesting for Self-powered Sensor Networks	Boise State University	$980,804	Researchers will develop high-efficiency and reliable thermoelectric generators (TEGs) for self-powered sensors utilizing thermal energy from nuclear reactors or fuel cycle. The project will identify suitable hot surfaces for TEG implementation, develop a robust TEG prototype with shielded package, and study the radiation effect on TEG properties and performances.
Enhanced Micro-Pocket Fission Detector (MPFD) for High Temperature Reactors	Idaho National Laboratory	$1,000,000	Researchers will develop, fabricate, and demonstrate the performance of enhanced Micro-Pocket Fission Detectors suitable for use as real-time reactor core neutron flux and temperature monitors in high-temperature advanced reactors.
Embedded Instrumentation and Controls for Extreme Environments	Oak Ridge National Laboratory	$1,000,000	Researchers will close critical technology gaps in instrumentation and controls (I&C) for advanced reactor designs. Crosscutting embedded instrumentation and control (I&C) technologies for extreme environments will be developed for a high temperature (700 °C) canned rotor pump testbed with active magnetic bearings and a switched reluctance motor.
Robust Online Monitoring Technology for Recalibration Assessment of Transmitters and Instrumentation	Pacific Northwest National Laboratory	$1,000,000	Researchers will create the next generation of online monitoring technologies for sensor calibration interval extension and signal validation in nuclear systems. The project will develop advanced algorithms for monitoring sensor/system performance and enabling the use of plant data to derive information that currently cannot be measured.
High Spatial Resolution Distributed Fiber-Optic Sensor Networks for Reactors and Fuel Cycle Systems	University of Pittsburgh	$987,676	Researchers will develop radiation-hard, multi-functional, distributed fiber optical sensor networks to improve the ability for sensors to actively adjust its sensitivity and functionality in time. This

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FY-15: NEET- 2 ASI FOA TOPIC: Digital Technology Qualification Demonstration for Embedded Digital Devices

Challenge: Demonstrate that embedded digital devices in NPP components can meet the digital technology qualification requirements

An embedded digital device is an electronic sub-component of a plant component (e.g. instrument or circuit breaker) which uses software or software-developed logic for some aspect of its operation.

The qualification method will demonstrate:

- **Cost-effective means of ensuring that the device is not subject to software common cause failure**
- **Application of these components in a realistic setting representative of actual NPP application**

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FY-15: NEET- 2 ASI FOA TOPIC: Digital Technology Qualification Demonstration for Embedded Digital Devices (Cont.)

Proposal Requirements:

- **Selected digital equipment shall be for multiple reactors or fuel cycle applications**
- **Project shall include a nuclear industry partner(s)**
- **Research shall address the following technical challenges:**
  - **Proof of acceptable software operational reliability**
  - **U.S. NRC regulatory requirements**
  - **Ability to detect defects introduced through the entire supply chain**
  - **Ability to dedicate commercial-grade devices for safety-related usage**
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Summary of NEET ASI Expected Outcomes

- 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.
- Organizations performing NEET ASI research are expected to produce 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.
- Research is **truly innovative and crosscutting** and yields sensors and instrumentation that offer the potential for **revolutionary gains** in reactor and fuel cycle performance and that can be applied to **multiple reactor designs and fuel cycle concepts**.

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

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Contact Information

Suibel Schuppner: suibel.schuppner@nuclear.energy.gov

Bruce Hallbert: bruce.hallbert@inl.gov