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FY17 ART I&C Program Overview and Objectives

NEET ASI Webinar
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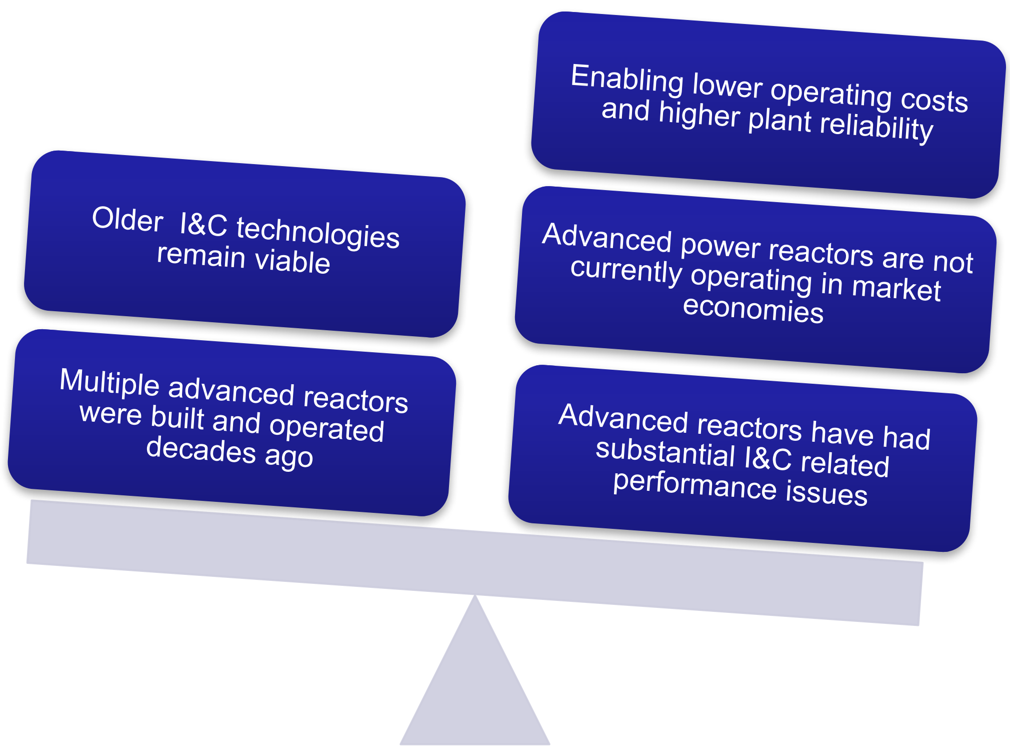
Where Does ART I&C Program Fit Within DOE-NE Reactor ICHMI Portfolio?

- **DOE-NE's reactor I&C and human-machine interface technology has three primary branches**
  - Advanced reactor technologies
    - Fast reactors
    - High temperature gas reactors
    - Molten salt reactors
    - Energy conversion
  - Nuclear energy enabling technologies
    - Advanced sensors and instrumentation
    - Spans reactors and fuel cycle technologies
    - Cross-cutting R&D
  - Light water reactor sustainability
    - Small modular reactors
    - Improved reliability, sustain safety, and extend the of LWRs

Why Have an Advanced Reactor I&C Program?

New I&C is Not Necessary for Functionality

Improved I&C is Necessary for Acceptable Performance



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Why Have I&C As a Cross-Cutting Program?

- **Many I&C issues are common to any advanced reactor**
  - More efficiently resolved by employing a common solution
- **I&C is an enabling technology consequently its issues are frequently not perceived to be the most pressing for any one reactor class**
  - Pooling needs enables I&C to receive adequate early attention
- **Regulatory requirements and industry standards are based upon common nuclear power safety issues not reactor class**

1. Developing common technologies to support automating maintenance and inspection activities within containment environments
2. Developing a common approach to instrumentation classification in high-passive safety reactors
3. Developing common technologies to provide optical access across containment boundaries
4. Developing a common approach to post-accident monitoring for reactors without grid access requirements

Emphasis of I&C Will Shift Towards Enabling Improved Performance In Future Nuclear Plants

More detailed condition and process knowledge

- Increasing automation – increased availability, lower staffing costs, improved grid transient response
- Maximizing component life
- Enabling improved component performance
- Support for safeguards

Increased passive safety

- Larger operating margins & slower accident progression facilitates use of complex digital logic
- Passive shutdown and passive decay heat rejection decrease safety significance of I&C (except for monitoring)

Deeply Integrated I&C Will Be a Key Difference Between Past and Future Nuclear Systems

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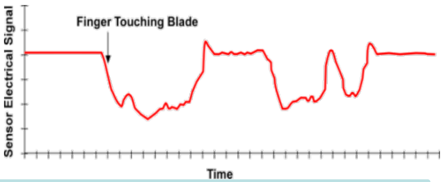
- **Sensors and controls have not typically been embedded in nuclear power reactor components**
  - High speed simulation and signal processing was not available in the first nuclear era
  - Dense sensor interconnection expands the set of degradation mechanisms that can be observed
- **Embedded I&C enables faster control reaction and increased stability in the event of component failures compared with traditional control**
  - Traditional approach to large component design is to include mass, large margins, and tolerate inefficiency as cost of doing business
- **Makes inherently unstable configurations stable ⇒ smaller, lower mass, lower cost, more reliable**
  - Railroad—AC traction drive locomotives enables 50% thrust increase
  - Industrial tools—Sawstop® prevents saw blade amputations
  - Aircraft/Aerospace—stabilizing fundamentally unstable wing configuration
  - Modern jet engines have experienced a 1000X reliability improvement with embedded I&C

Locomotive AC Traction Motors



Sawstop® Blade Current Signal

Delta Wing Aircraft

Instrumentation is Central to Monitoring Fissile Material Location for Safeguards

- **Nuclear material must be accounted for at each stage of operations**
  - Material balance measurements and key measurement points are central to safeguards
- **Some advanced reactors embed more of the fuel cycle into reactor facility**
  - Integral fast reactor
  - Molten salt reactors
    - Current safeguards implementations do not address implications of fluid fuel forms
- **Additional monitoring likely to be required that doesn’t exist today**
  - Item counting and visual accountability of fuel may not be possible

> Safeguards are the technical means for the IAEA to verify that States are meeting their legally binding undertaking not to use nuclear material or other items for illicit purposes

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Improved I&C is a Key Element of Achieving Program Missions

Operations & Maintenance

- Automated/remote maintenance & inspection
- Highly responsive load following
- Shorter outages - diagnostics
- Automating security functions

Lower Costs

Process Measurements

- Distinctive coolants (opaque)
- Higher temperatures (increased corrosion)
- Integration with process heat users
- Test facility instrumentation

Improved Performance

Condition Monitoring

- Avoid unplanned outages
- Functionality of passive safety SSCs
- Fuel performance
- Remaining life evaluation

Greater Certainty

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I&C Projects Also Support NE and ART Initiatives

Advanced Test/Demo Reactor
- I&C architecture development
- Operations & Maintenance Planning

Accelerated Commercial Deployment
- GAIN advanced reactor instruments
- Monitoring / automating TRISO fuel manufacturing
- MCFR process instrumentation

Regulatory Technology Support
- In-core hot spots
- Primary circuit circulating radioactivity
- Safety feature functionality


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INL/EXT-14-32837

Plan

Project No. 29980

Advanced Reactor Technology - Regulatory Technology Development Plan (RTDP)

INL Idaho National Laboratory

Johnson Noise Thermometry for Drift-Free Temperature Measurements

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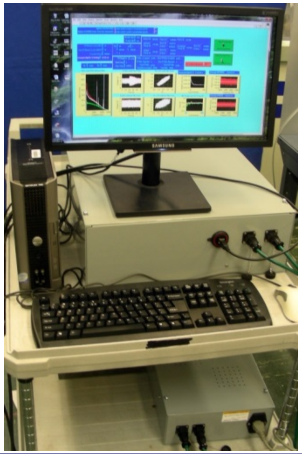
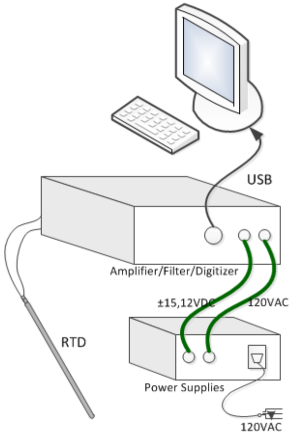
Relevancy

- **Instrumentation naturally drifts from calibration over time and each channel must be periodically visited, inspected, and recalibrated.**
  - Any potential drift in the primary loop temperature measurement must be accounted for in the operating margin. Hence, decreasing the temperature measurement uncertainty can directly increase the plant revenue.





Technical Approach/Accomplishments/Results

- **New Johnson Noise Thermometry system developed**
- **All hardware and software is complete**
- **Tested electromagnetic interference (EMI) effects on the system**
- **Tested at Sandia and at Kingston Steam Plant**

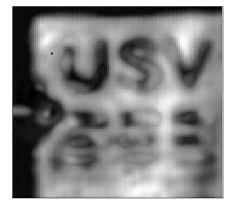
Expected Deliverable & Schedule

- **Project is complete**
- **ORNL/TM-2016/301 provides project details**

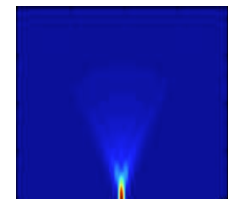
Under Sodium Viewing - ANL

- **Developing an enabling under sodium viewing (USV) technique for nondestructive examination (NDE) of SFRs:**
  - Real-time operation or maintenance monitoring of SFR at high temperatures and high radiation in-sodium
  - In-service inspection and repair of components, structures, and systems within reactor core or steam generators

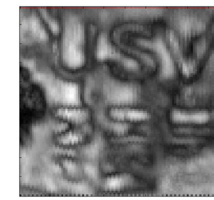
UWT (in Sodium @ 177°C)



BUWT-PA



Submergible HT-UT (in Sodium @ 343°C, potential up to 550°C)



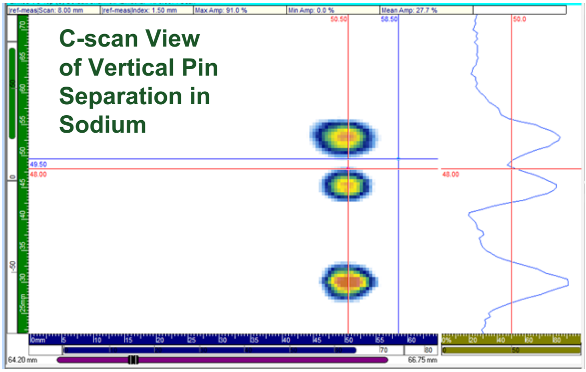
Technical Approach/Accomplishments/Results

- Constructed a USV test facility for automated in-sodium test, signal/image processing, and defection detection.
- Successfully demonstrated ultrasonic waveguide transduce (UWT) technique with real-time detection resolutions of 0.5 mm in both width and depth up to 343°C in sodium.
- Successfully demonstrated submergible high-temperature transducers with real-time detection resolutions of 0.5 mm in depth and 1 mm in width up to 343°C in sodium.
- Developed a brush-type ultrasonic waveguide transducer phased array (BUWT-PA). Water mockup has shown real-time detection resolutions of 0.5 mm in depth and 0.5-2 mm in width (scanning methods).

- Development of submergible HT transducers
- Development of BUWT phased array
- In-sodium test of submergible HT transducers and BUWT phased array
- Identify commercial partners and in-reactor USV system integration pathways

Under-Sodium Viewing - PNNL

- **Ultrasonic Testing for Under Sodium Viewing to:**
  – Monitor operations in optically opaque sodium at high temperatures
  – Nondestructively inspect structures, systems, and components within the reactor.

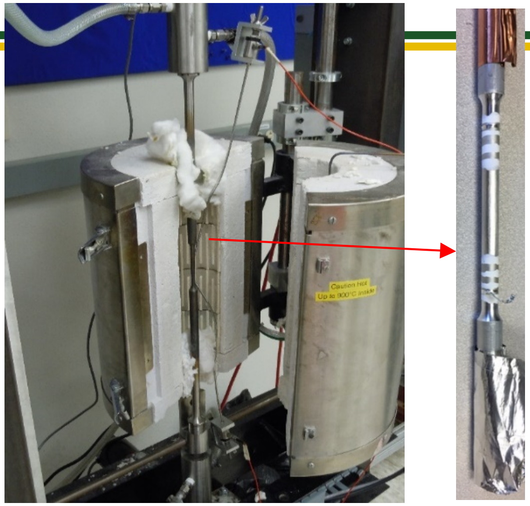


- **Wrap-up and freeze PA-UT probe designs**
  – Develop formalized design documentation
    - *Linear and matrix-array probe designs*
  – Develop technology transfer materials
  – Complete IP protection (patent submission) and export control reviews
  – Identify and engage potential commercial partners
    - *Complete nondisclosure agreements and hold technical discussions*
- **Complete image reconstruction/signal processing study for improving signal-to-noise ratio, image-based detection and characterization in-sodium**

- **Complete export control analysis (Near Completion)**
- **Protect IP, submit patent (In-Progress)**
- **Engage viable commercial partners (In-Progress)**

Measurement Technologies for Prognostic Indicators for Advanced Reactor Passive Components

- **Enhanced awareness of AdvRx component condition to improve asset protection and lifetime degradation management, optimized O&M activities, extended operating cycles, and extended reactor life**
  - Detection of early stages of degradation in inaccessible or hard-to-replace passive components key to safe operation of AdvRx
  - Identification of measurement technologies that provide early indicators of damage in passive components and reactor internals
  - Evaluation of in-situ measurement sensitivity and effectiveness



- **FY2017 focus on** sensor design, fabrication, and assessment of inspection capability for in-situ online monitoring of selected degradation modes
  - Technical approach uses a combination of simulation modeling and experimental assessment of selected in-situ nondestructive measurements for their sensitivity and reliability
- **Accomplishments/Results:**
  - Target components and degradation mode identified; experimental plan draft completed
  - Insights into likely in-situ measurement options in AdvRx
  - Probe designs being finalized and fabrication initiated
  - Ongoing/planned efforts focus on completing probe fabrication for high-temperature in-situ monitoring, and quantification of performance

- **Complete initial evaluation of in-situ measurement of AdvRx passive component prognostic indicators**
- ***Complete sensor design and fabrication***
- ***Complete initial experimental assessment of in-situ monitoring options, with a focus on sensitivity and measurement uncertainty***

High Temperature Fission Chamber

- **Objective – Design, build, and demonstrate a high temperature fission chamber**
- **HTFC Fabrication**
  - Irradiation test plan and transportation plan under completed
  - 100% of parts received
  - High temperature preliminary experiment at ORNL completed
  - Activation analysis of detector and test assembly completed
- **HTFC Electronics**
  - Noise analysis of furnace power supply completed
  - DAQ ordered and control software started

Temperature Experiment

Instrumentation Will Continue to Form the Nervous System of Future Nuclear Power Plants

- **Instrumentation remains an enabling technology**
  - Traditional instrumentation technologies remain viable
  - Lowering costs and increasing reliability requires improved I&C
- **Integrating I&C into the plant design is key to effective operations & maintenance as well as safeguards**
- **Diagnostics & prognostics can facilitate limited lifetime components**