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ART ICHMI R&D Overview

DOE NE Advanced Sensors and Instrumentation Webinar
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Sacit Cetiner
for David Holcomb
ART ICHMI Technical Area Lead

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 (ART)
    - Fast reactors
    - High temperature reactors
    - Advanced reactor generic technologies
  - Nuclear Energy Enabling Technologies (NEET)
    - Advanced Sensors and Instrumentation (ASI)
    - Spans reactors and fuel cycle technologies
    - Cross-cutting R&D
  - Light-Water Reactor Sustainability (LWRS)
    - Small modular reactors
    - Improve reliability, sustain safety, and extend the lifetime of LWRs

DOE Provides Multiple Layers of Guidance on Program Objectives

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DOE-NE Mission
Resolve barriers to advanced nuclear reactors becoming national resource

- Uncertainty in plant reliability and safety performance
- High operating and security costs
- Uncertainty in licensing cost and schedule

ART Mission
Develop concepts with potential to be safer, less waste producing, more cost competitive, and more proliferation-resistant

- Fast reactors
- High temperature reactors
- Advanced reactor generic technologies
- Advanced reactor regulatory framework
- Advanced reactor system studies

Field Budget Guidance
supporting objectives

- Substantial industry interactions
- Substantive international collaborations

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

Operations & Maintenance

- Automated/remote maintenance
- 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
- Improved fuel performance
- Remaining life evaluation

→ Greater Certainty

I&C Projects Also Support NE and ART Initiatives

Advanced Test/Demo Reactor
- Measurement and instrumentation requirements
- 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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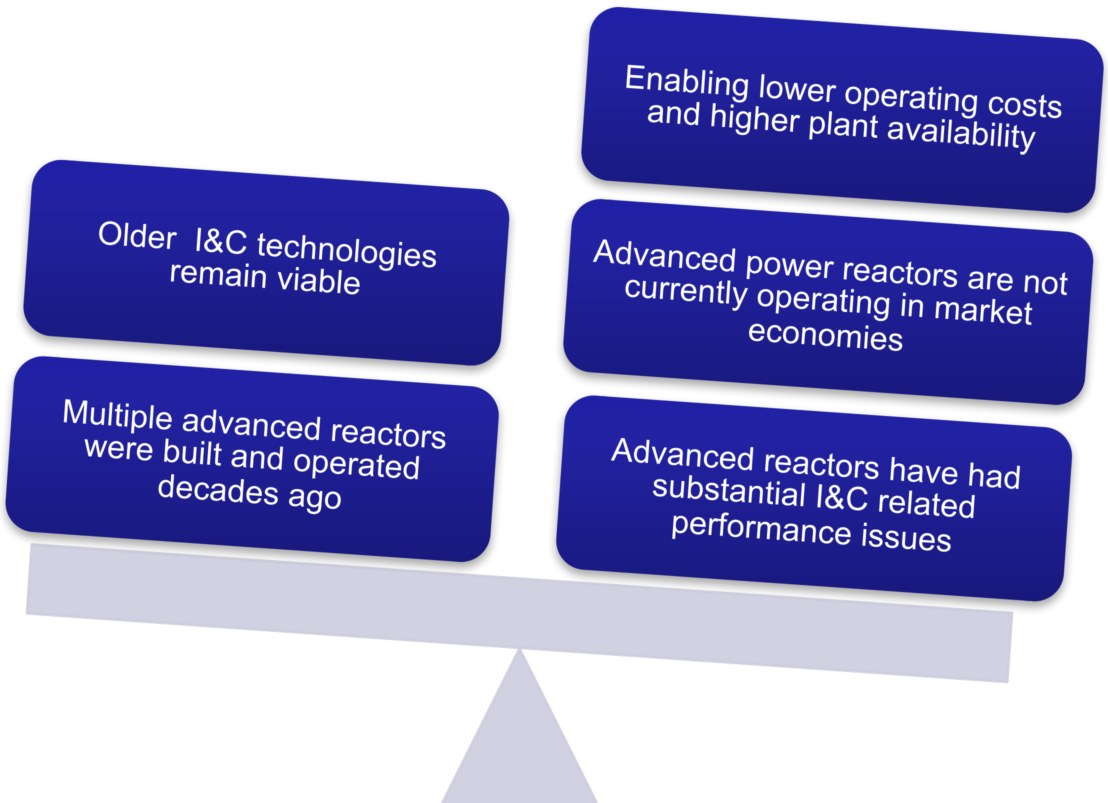
Why Have an Advanced Reactor I&C Program?

New I&C is not Necessary for Functionality

Improved I&C is Necessary for Acceptable Performance



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Sensor Technology Assessment for Advanced Reactors (STAAR) – ORNL, PNNL, ANL

- **Goal of the STAAR project is to identify gaps in sensor technologies that can lead to improved safety, reliability, or economics for advanced reactors**
  - Scope includes both high temperature reactors and fast reactors
  - Cooperatively performed by ORNL, ANL, and PNNL with input from INL
  - This project was completed in August 2016
- **Outcome of the project will be an enhanced technology basis for identifying and prioritizing research targets within the I&C technology area**
- **Significant progress in instrumentation technology has occurred since operation of the last gas and liquid-metal reactors in the US**
  - New measurement technologies – acoustics, microwaves, optics
  - New measurement processes – organic molecules, electrochemical species
  - Advanced electronics and signal processing
- **Synthesizing new measurement capabilities to address past limitations and unmet needs**

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STAAR Project Supports the Overall ART Mission – ORNL (AT-16OR230107), PNNL (AT-16PN230108), ANL (AT-16AN230109)

ART PROGRAM

STAAR Project

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Other ART projects

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Other ART Projects

Sensor technology target application areas that arise from the STAAR project

Order of magnitude improvement (or introduction of new)…

- Nuclear and process measurement technologies
- Moisture detection
- Fuel leak detection
- Remote robotic repair and maintenance in containment
- etc., …….

IMPACT OF STAAR PROJECT ON AdvRx DESIGN

Identify gaps in sensor technology and map a path for sensor research with objectives including the following:

- Increased safety margins
- Improved reactivity control
- Prevention of fuel oxidation and corrosion
- Improved heat transfer and efficiency
- Capability to maintain critical components in a hostile environment
- etc., …..

ART PROGRAM

ART Regulatory Technology Development Plan (ART-RTDP):

- "Links research activities (ART Program) to key regulatory requirements and licensing challenges likely to affect deployment of Advanced Reactors (AdvRx)"

- Facilitates licensing of advanced reactor designs
- Supports update and/or development of new standards

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Enhanced Risk Monitors with Integrated Equipment Condition Assessment – PNNL (AT-16PN230105)

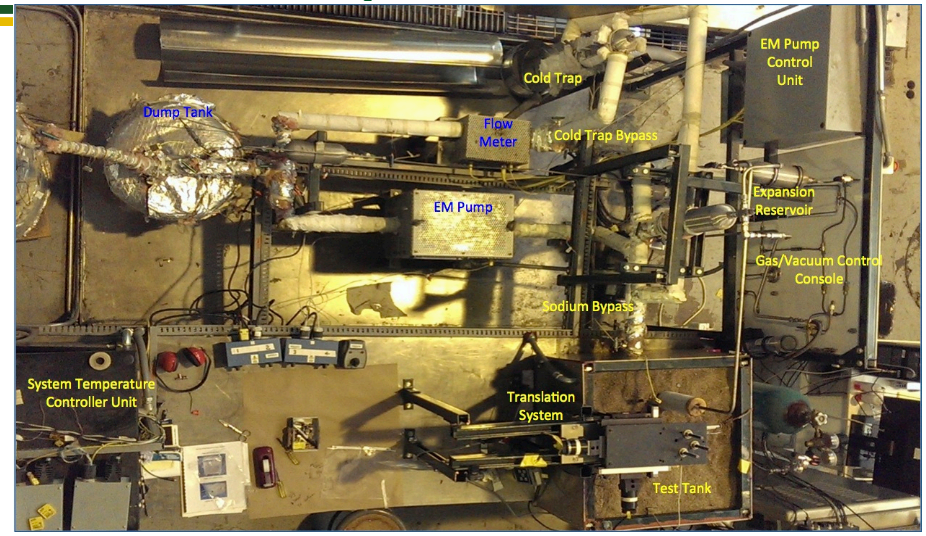
- **Integrate dynamic health assessment of key active components with risk monitors to provide real-time estimates of predictive risk**
  - Provides predictive estimates over a specified time horizon of safety margins when operating with components with detected degradation
  - Provide a mechanism for optimizing plant performance to maintain safety margins while maximizing return on investment
  - Inform O&M decisions to target specific maintenance activities during upcoming outages
  - Support extended operating cycles by ensuring reliable component operation over the long term
- **Technical challenges were addressed in FY2016**
  - Integration of software modules for enhanced risk monitors with ORNL supervisory control platform for demonstration of ERM technologies
- **This project was completed in August, 2016**

Supervisory Control of Multi-Modular Advanced Reactor Plants – ORNL (AT-17OR230201)

- **A supervisory control system can potentially**
  - **help reduce control room staffing size**
    - an autonomous control capability can reduce demand of human resources, particularly for day-to-day operational activities, through enhanced monitoring (i.e., diagnostics and prognostics) and built-in decision-making (i.e., incorporation of actual status of physical plant into decision-making)
  - **help facilitate integration of highly complex systems, such as multi-unit plants and hybrid energy systems**
    - automated decision-making capabilities can be an enabling technology for systems that share multiple product streams
    - advanced features may include automatic unit startup, automatic load-following, automatic load allocation, and autonomous handling of component faults and degradation (i.e., predictive and proactive operation strategy rather than reactive)
- **Autonomous decision-making capabilities are not commercially available; and will significantly advance the *state-of-the-art* of controls**
- **This project will be completed by November 30, 2016**

Under Sodium Viewing (USV) – ANL (AT-17AN230101)

USV Test Facility

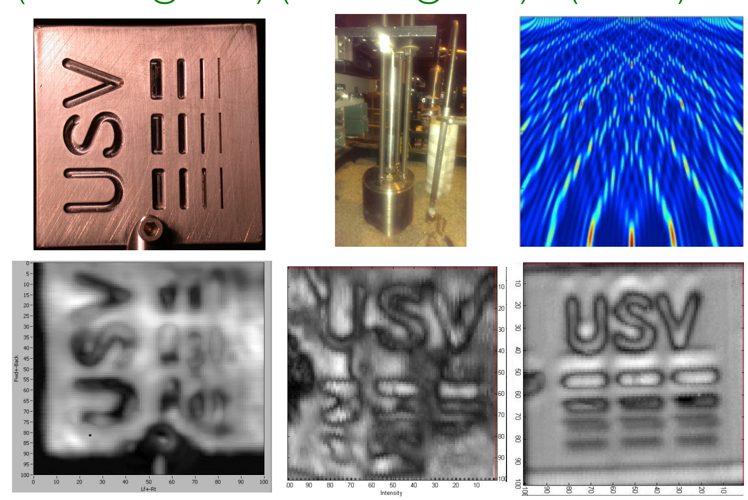


Subtask Relevancy

- Develop an enabling USV technique for real-time operation monitoring and nondestructive examination (NDE) of SFRs:
  - Real-time operation and maintenance monitoring of SFRs at high-temperature and high-radiation environment in sodium
  - In-service inspection and repair of components, structures, and systems within reactor core or steam generators
  - Improve reliability, ensure safety, and reduce operational costs
  - Benefit inspection needs of various industries, particularly those requiring inspection/monitoring in harsh environment
- Working with Westinghouse for the use of the USV facility to test and validate thermoacoustic sensors for monitoring temperature and neutron flux in SFRs
- CEA-DOE-JAEA collaboration on In-Service Inspection and Repair (ISI&R)
- Working with Westinghouse on potentially developing an under-lead viewing system for in-reactor surveillance of lead-cooled fast reactors

Real-Time Intensity Images

UWT (in Sodium @ 350°F) | Submergible UT (in Sodium @ 320°F) | BUWT-PA (in Water)



Under Sodium Viewing (USV) – PNNL (AT-17PN230102)

- **Development and demonstration of advanced ultrasonic phased array probes and inspection techniques advances state-of-the-art in under sodium NDC**
  - Directly supporting the design and development of technology advancements that underpin SFR inservice inspection (ISI) through NDE
  - Developing a firm scientific and engineering-based foundation for enabling effective and reliable operation of advanced NDE sensors in sodium-cooled fast reactors (SFRs)
- **Furthering the body of knowledge and developing innovative NDE technologies that address feasibility and performance challenges (monitoring structural integrity, detecting loose parts, monitoring degradation and generating feedback for service-life prognostics)**
- **Advancing the scientific understanding of the operability and performance of NDE probes/sensors in high temperature, corrosive environments**
- **Supporting the development of advanced instrumentation, controls and human-machine interfaces that can improve safety and enhance operational confidence**

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High Temperature Fission Chamber – ORNL (AT-17OR230104)

- **Fission chambers are key instruments for measuring neutron flux at nearly all nuclear reactors**
  - Startup of high temperature reactors is challenged by difficulty of monitoring approach to criticality
  - Employing materials compatible with most advanced reactor coolants
- **FHR-DR was selected as a reference reactor because it operates at a peak coolant temperature of 700°C and has a high fission power density**
  - FHR-DR point design was recently completed under the ART program
  - Several computational models were recently developed and are available at no cost
- **Potential for international collaboration for demonstration in operating advanced reactors**

Johnson Noise Thermometry – ORNL (AT-17OR230106)

- **Stable and reliable instrumentation is needed for effective advanced reactor operations**
- **Instrumentation naturally drifts from calibration over time and each channel must be periodically visited, inspected, and recalibrated**
  - Extended fuel cycles decrease the opportunities for thermometer calibration
- **Redundant measurements are used to improve accuracy but still require expensive maintenance intervals**
- **Any potential drift in the primary loop temperature measurement must be accounted for in the operating margin**
  - Desire for higher plant efficiency results in operation nearer to plant thermo-mechanical margins
  - Reactor excursion outside of design temperature range may result in severe consequences

Measurement Technologies for Prognostic Indicators for Advanced Reactor Components – PNNL (AT-17PN230103)

- **Project objectives: In-situ nondestructive measurement technologies for detecting early stages of degradation in hard-to-access/hard-to-replace passive components**
  - Enhanced asset condition awareness and early warning of loss of integrity by measuring key indicators of degradation
  - Greater understanding of precise plant component conditions, leading to improved estimates of margins to failure
  - Reduced labor demands arising from current requirements for periodic equipment surveillance and inspection
  - Enable condition-based maintenance activities, which support lifetime degradation management and a science-based justification for extended plant lifetime
- **Technical challenge being addressed in FY2016 and FY2017**
  - In-situ sensor environmental compatibility, design for high sensitivity to expected degradation mechanisms and measurement reliability