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Advanced Small Modular Reactor Research and Development– Instrumentation, Control, and Human-Machine Interface (ICHMI)

Overview

AdvSMR ICHMI FY14 Status and

Transition to Advanced Reactor Technologies Program

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Presented during

DOE Combined Review Meeting for I&C Research

U.S. Department of Energy – Webinar

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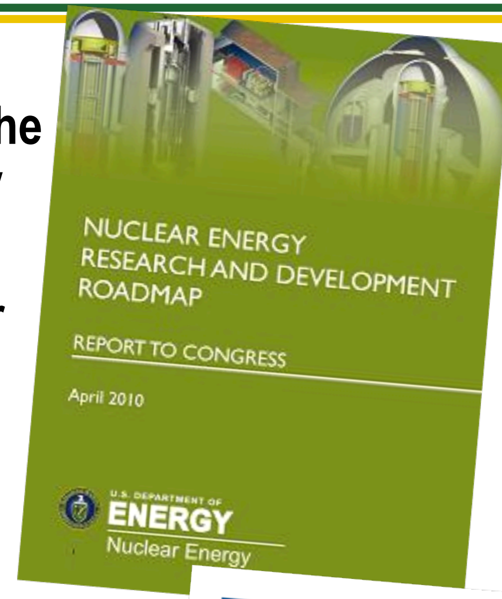
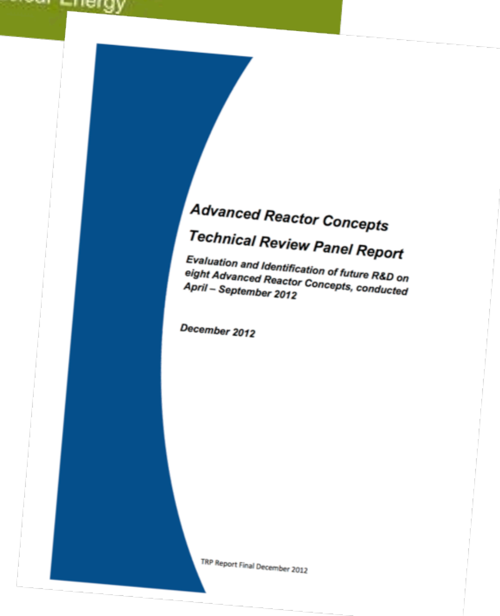
ICHMI Technical Area Focus is on Achieving Goals and Resolving Challenges for Advanced Reactors

- **DOE-NE R&D Objective #2 [Develop improvements in the affordability of new reactors…] establishes the primary goal for ART ICHMI research**
  - ICHMI is the equivalent of the central nervous system for nuclear power plant and contributes significantly to
    - Achieving cost-competitiveness
    - Ensuring safety
    - Enabling licensability for operation
- **Advanced Reactor Concepts TRP Report lists some ICHMI-related technical issues requiring resolution to establish an Advanced Reactor Licensing Framework**
  - Multi-module control
  - Staffing of smaller units or modules
- **ICHMI R&D specifically targets challenges associated with unique operational and process characteristics of advanced reactor concepts**





ICHMI R&D Priorities are being Adapted for Transition from AdvSMR to ART

- **Research priorities**
  - **Address technology gaps (e.g., sensors)**
  - **Resolve key technical and licensing issues**

- **Key research targets**
  - **Environment, architecture, and dependability for critical measurements and in-vessel monitoring**
  - **High-fidelity condition determination and incipient failure detection to support extended operation**
  - **Flexible, robust automation for off-normal conditions and multi-unit operation**
  - **Reduced human resource demands for operations and maintenance**

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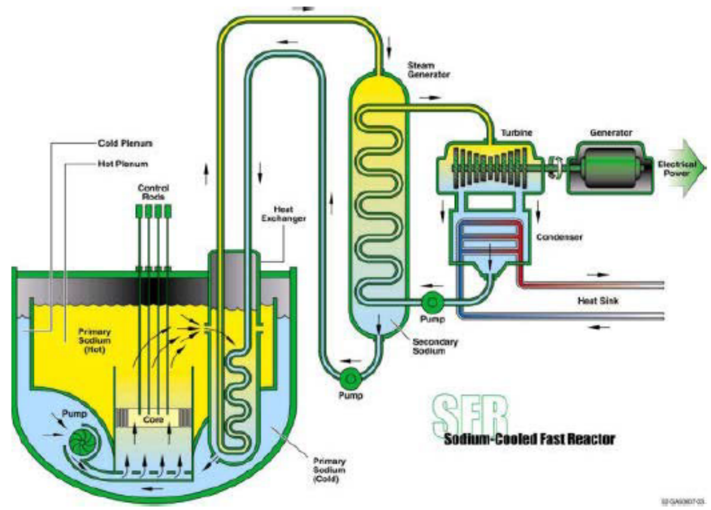
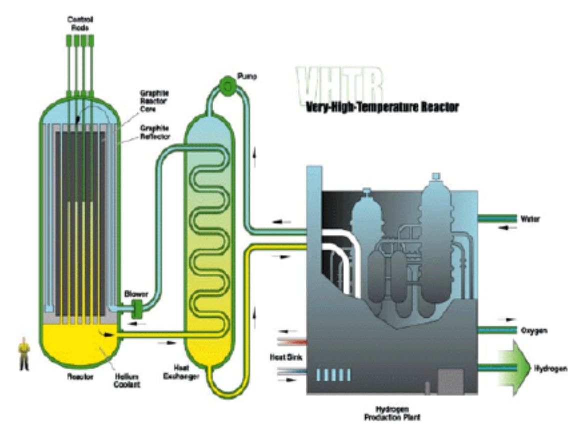
ICHMI R&D Priorities are being Adapted for Transition from AdvSMR to ART

- **Research priorities**
  - Address technology gaps (e.g., sensors)
  - Resolve key technical and licensing issues

Sensors	↑
O&M Efficiency/Staffing	↓
Automation	↓
Diagnostics/Prognostics	←→



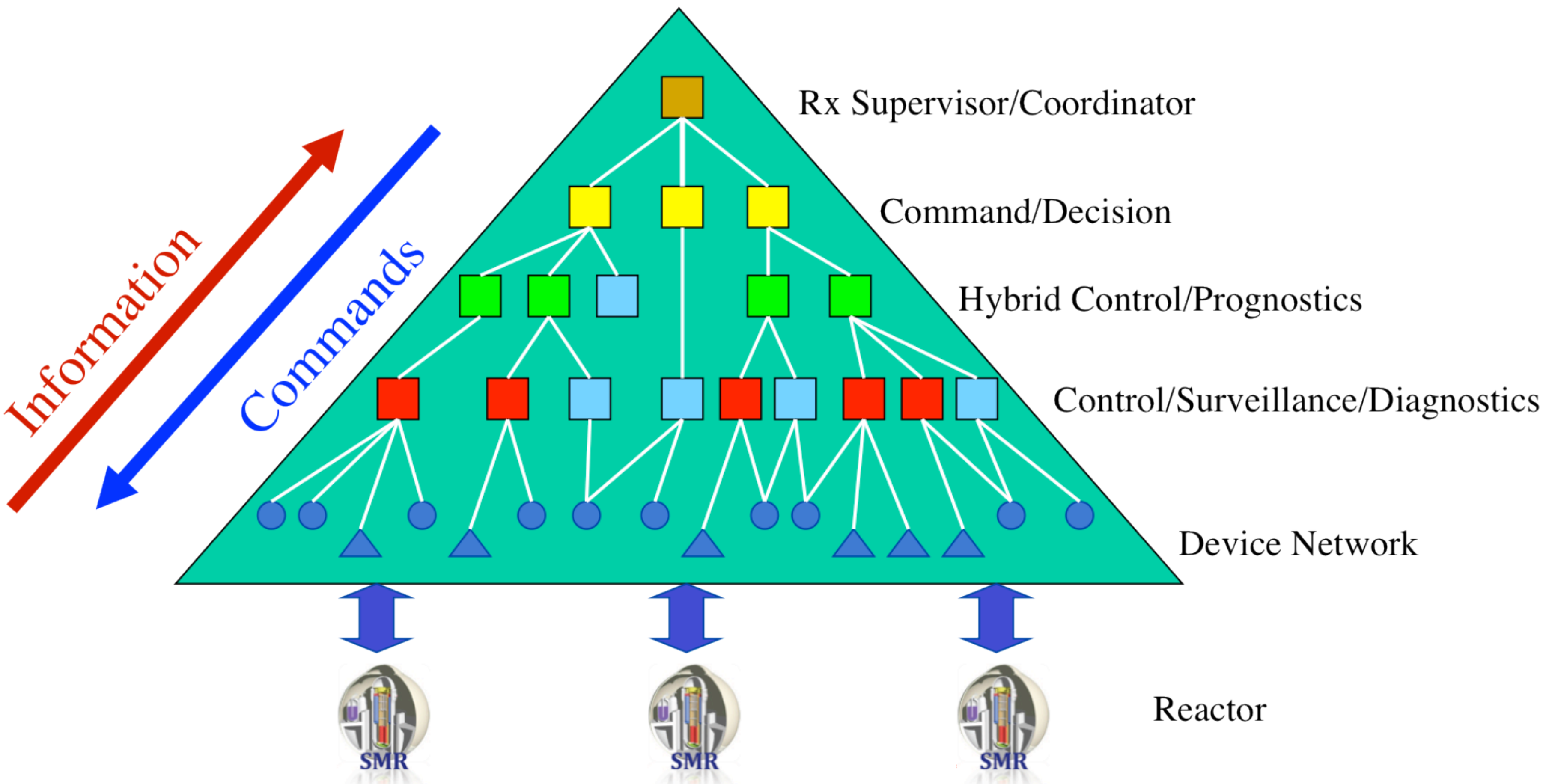
- **Key research targets [Observability and Operability]**
  - Environment, architecture, and dependability for critical measurements and in-vessel monitoring
  - High-fidelity condition determination and incipient failure detection to support extended operation
  - Flexible, robust automation for non-traditional operation (multi-unit, integrated energy systems), including off-normal conditions and events
  - Optimized human resource utilization for safe and cost-effective operations and maintenance



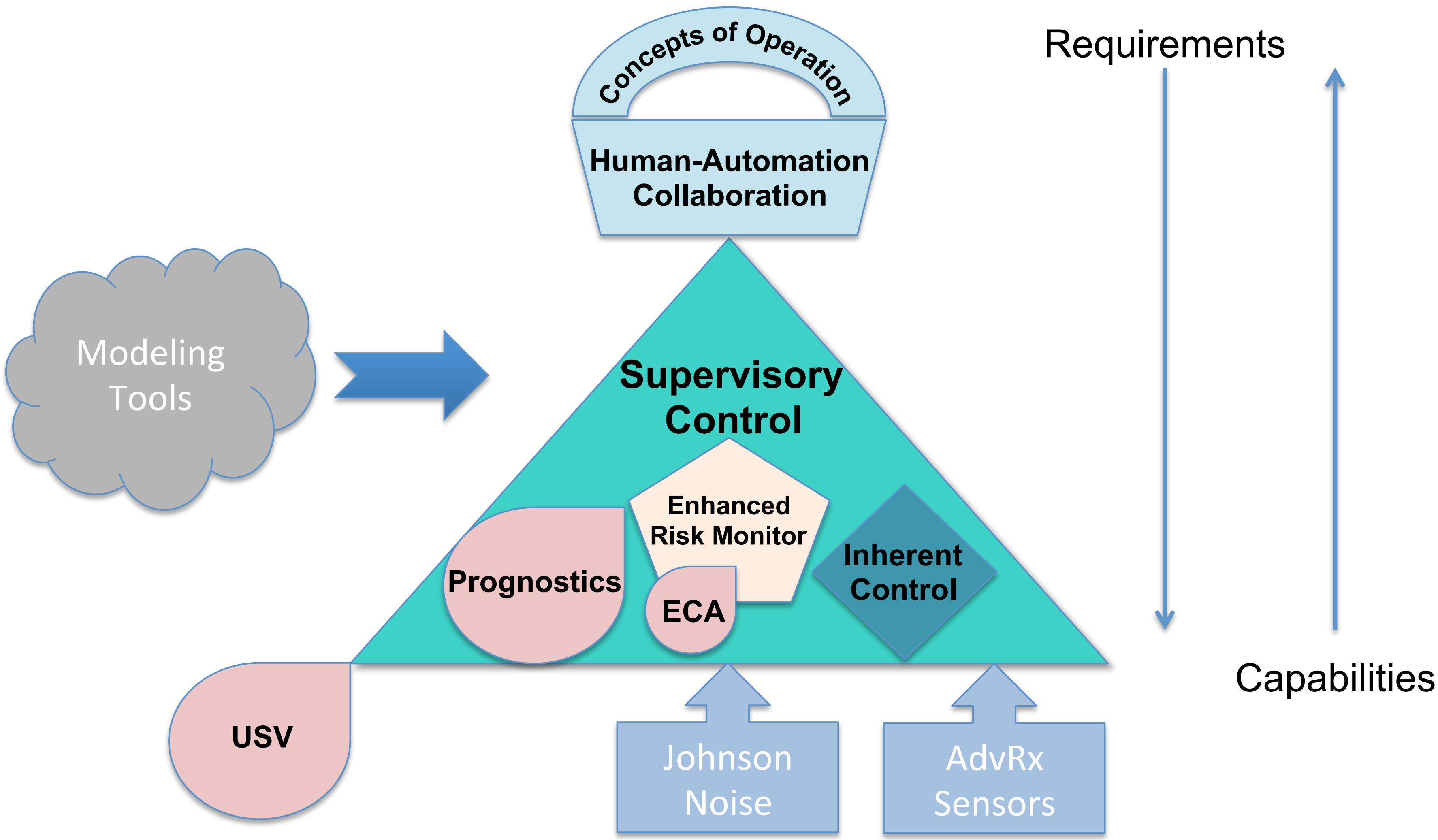
There are 10 I&C Projects Underway in FY14 [AdvSMR & ARC]

- Johnson Noise Thermometry for Drift-Free Temperature Measurements
- Concepts of Operation for Multi-Modular SMR Plants
- Framework for Human-Automation Collaboration
- Supervisory Control of Multi-Modular SMR Plants
- Impact of Active Control on Passive Safety Characteristics of Advanced SMRs
- Prototypic Prognostic Technique Demonstration for SMR Passive Components
- Enhanced Risk Monitors with Integrated Equipment Condition Assessment
- Modeling Tools for Dynamic Behavior Simulations of SMRs
- Waveguide Transducer Assembly for Under-Sodium Viewing
- Submerged Transducer Assembly for Under-Sodium Viewing

Technology Context for AdvSMR ICHMI Challenge



Interrelated Projects Address Key Parts of ICHMI Challenge



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Overview and Status Presentations To Follow

- Johnson Noise Thermometry for Drift-Free Temperature Measurements
- Concepts of Operation for Multi-Modular SMR Plants
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- Supervisory Control of Multi-Modular SMR Plants
- Impact of Active Control on Passive Safety Characteristics of Advanced SMRs
- Prototypic Prognostic Technique Demonstration for SMR Passive Components
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Work Package SR-14OR130106 – Johnson Noise Thermometry for Drift-Free Temperature Measurements

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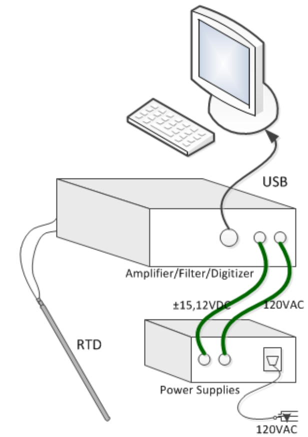
Task Relevancy

- **Instrumentation naturally drifts from calibration over time and each channel must be periodically visited, inspected, and recalibrated.**
  - Drift in the primary system temperature measurements must be addressed in operating margin and by periodic maintenance
  - Decreasing the temperature measurement uncertainty/ calibration demands can directly increase the plant revenue

JNT Prototype



Technical Approach/Accomplishments/Results

- **Develop Johnson Noise Thermometry system prototype**
- **Self-calibration of traditional RTD measurement accomplished based on Johnson noise measurements over time**
- **Innovative noise rejection algorithms devised and under test**
- **Field test underway at HFIR with additional field tests planned**
- **Demonstration of self-calibration capability is proceeding**

Expected Deliverable & Schedule

- **JNT prototype developed and laboratory tested [FY13]**
- **Environmental effects (EMI/RFI) testing conducted [FY13-14]**
- **Field demonstration scheduled at multiple venues [FY14-15]**
- **Self-calibration capability demonstration [FY15]**
- **Technology transfer planned for commercialization**

Work Package SR-14OR130107 – Supervisory Control of Multi-modular SMR Plants

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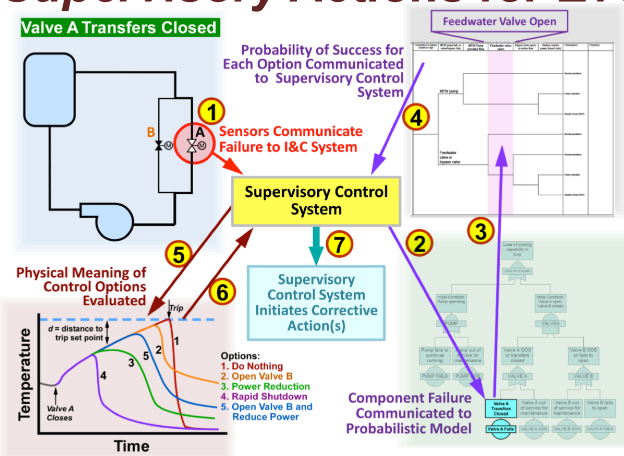
Task Relevancy

- **Adoption of a supervisory control system concept in advanced nuclear systems will support their economic competitiveness. Moreover, they will facilitate integration of these systems within hybrid energy clusters**
  - Commercial control systems are able to perform tasks from a limited set of automation rules. However, they fail to execute complex tasks that require situation analysis and decision-making
  - Supervisory control concept, as developed by ORNL, advances the state of the art by incorporating decision-making into a hierarchical control system architecture

Supervisory Actions for Event



Technical Approach, Accomplishments/Results

- **Supervisory control system is conceptualized as a non-safety system that is completely isolated from reactor protection system**
  - Trip setpoints define the control domain
  - This approach makes the licensing case easier
- **Decision-making is achieved in a two-tier approach**
  - **Probabilistic portion** uses PRA in real time
    - generates available alternative scenarios
    - provides metric for ranking
  - **Deterministic portion** uses utility theory
    - applies deterministic rules
    - Incorporates other features, such as anticipated component stress, into decision-making

Expected Deliverable & Schedule

- **Devise supervisory control requirements and develop functional architecture [FY13]**
- **Implement the first-of-a-kind probabilistic decision-making capability for supervisory control [FY14]**
- **Implement the first-of-a-kind deterministic decision-making capability for supervisory control [FY15]**
- **Develop and demonstrate a fully-functional decision-making capability for supervisory control [FY15]**

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Work Package SR-14AN130101 – Impact of Active Control on Passive Safety

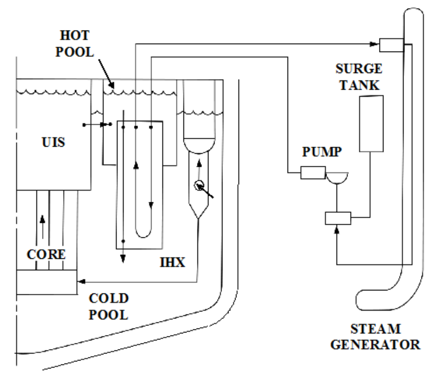
Task Relevancy

- **AdvSMR operational flexibility is important**
  - Multiple units, high penetration of renewables
  - Backbone of a small regional grid – Limited fossil
- **Black re-start capability required**
  - If islanded, meet house load without dependence on emergency power => Fast runback
- **Control system failure or operator error should not override safe inherent regulation**

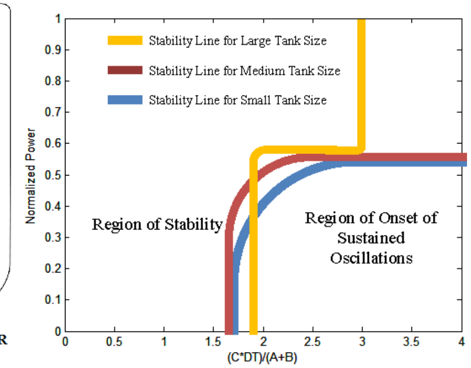
Technical Approach, Accomplishments/Results

- **Limit actuator input and initiator size**
  - Developed protocol for coordinating plant design and control system design to achieve this
- **Worked through full power case for SFR**
  - Fuel conductivity is a key parameter for protection against inadvertent over-ride of inherent safety
- **Post fast-runback is the limiting case**
  - Developed passive control scheme to minimize risk of initiator for islanded plant
  - Characterized plant stability from first principles
  - Demonstrated good stability margin for metal fuel

Stability Characteristics



Representative AdvSMR



Stability Map

Expected Deliverable & Schedule

- **Perform simulation-based analysis of passive characteristics and impact of active control actions [FY13]**
- **Investigate inherent controlability characteristics of representative SMR [FY14]**
- **Perform comparative study of control and protection system performance [FY15]**

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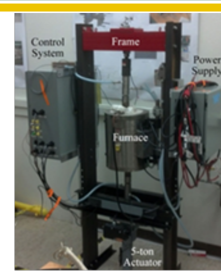
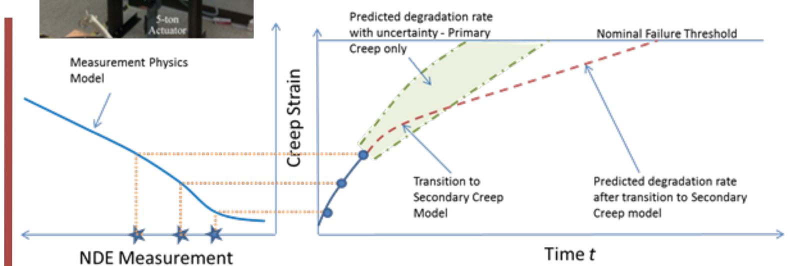
Work Package SR-14PN130110 – Prototypic Prognostic Technique Demonstration for SMR Passive Components

Task Relevancy

- **Enhanced awareness of component condition and predictive estimates of (passive) component failure customized for each unit**
  - Early warning of potential degradation in inaccessible passive components leading to failure in advanced reactor environments
  - Compensate for limited knowledge of physics of failure mechanisms in advanced reactor environments
- **Tools to enhance and optimize O&M of AdvSMRs to help compensate for economy of scale losses**

Local-level Prognostics





Technical Approach, Accomplishments/Results

- **Prognostic health management (PHM) for AdvSMR passive components using NDE measurements of degradation state as input**
  - Focus on local-level and component level prognostics as defined in the research plan
  - Enhancement of local-level prognostics algorithms for passive components to incorporate advanced methodologies, including uncertainty propagation and lifecycle prognostics.
- **Initial PHM algorithm development complete**
- **Experiments for PHM algorithm validation ongoing, using high temperature creep as prototypic degradation mechanism**
  - Developed conceptual design of test-bed to evaluate prognostic algorithms for mechanisms of relevance

Expected Deliverable & Schedule

- **Complete Local-Level prognostics algorithm development for AdvSMR passive components. – 9/12/2014**
- **Complete component-level prognostics health management framework development – FY2015**
- **Framework to integrate multiple component-level PHM systems for comprehensive plant-level health indicators – FY2016/FY2017**

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Work Package AR-14PN230102 – Submerged Transducer Assembly for Under-Sodium Viewing

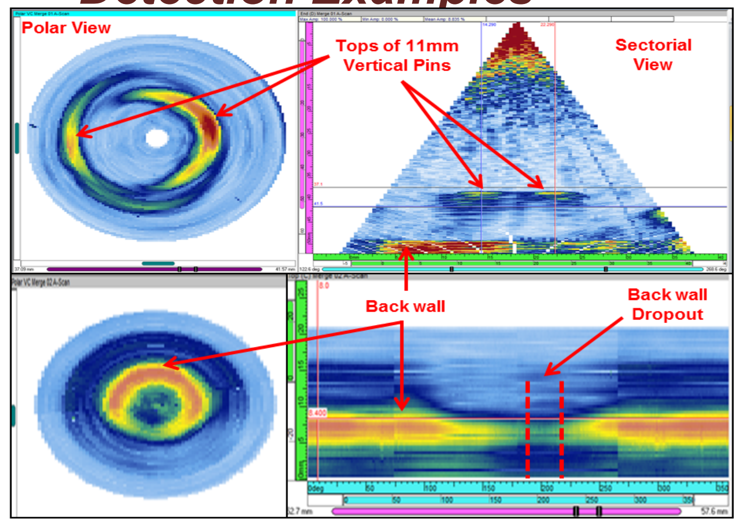
Task Relevancy

- **The need to re-establish domestic technology infrastructure to support the deployment of SFR technology has been identified**
  - A key enabling nondestructive examination (NDE) technology is 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.*

Detection Examples

H_20

Na



Technical Approach, Accomplishments/Results

- **Designed and tested prototype SN2, linear phased array probe. Many lessons learned.**
  - Improvements (from SN1 probe) in reliability, resolution, robustness, sensitivity, and SNR were achieved.
  - Temperature effects, sodium impurity issues, and wetting of the probe face have been successfully addressed.
- **To address existing image resolution challenges**
  - 2-D matrix array design (for SN3 prototype probe) will be tested and demonstrated in FY15
  - Fabricate/demo (2) pre-manufacturing SN3 prototype probes
  - Initiate commercialization/tech-transfer of SN3 probe

Expected Deliverables & Schedule

- **Model/simulate 2-D array matrix and optimize beam steering characteristics and focal dimensions**
- **Fabricate and test SN3 prototypes**
- **Document in-sodium PD protocol and results for SN3 prototypes (04/15)**
- **Tech-transfer package (05/15)**
- **Identify commercial partner and reach tech-transfer agreement (08/15)**
- **Final M2 report - FY15 activities (09/15)**

AdvSMR ICHMI & ARC I&C Now Incorporated in ART Program

- **Existing research advances state of the technology for addressing critical ICHMI needs to ensure AdvSMR are economically viable and licensable**
  - Reduce O&M costs and develop technical basis for regulatory acceptance [innovative Concepts of Operation, efficient Human-Automation collaboration, increased automation and effective inherent control, reduced maintenance and surveillance burden]
- **FY15 technical area strategy for programmatic transition**
  - Adjust I&C research priorities based on defined focus for combined Advanced Reactor Technologies Program (Fast Reactors, High Temperature Reactors)
  - Emphasize gap resolution for Observability technologies [sensing, inspection and prognostics research]
  - Conclude Operability research focused on longer term, more generic issues
    - Take current projects to logical conclusion
    - Identify opportunities for eventual transition of research topics to NEET ASI or application to specific designs
  - Identify future research targets to proceed with addressing technology gaps