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

Advanced Sensors and Instrumentation

Cost-Benefit Analyses through Integrated Online Monitoring and Diagnostics

Advanced Sensors and Instrumentation (ASI)
Annual Program Webinar
October 24 – 27, 2022

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Project Overview

Project Goal: Improve advanced reactor economics through:

- Optimization of the reactor sensor network design
- Intelligent asset-management decision-making during operation

Participants

PI: Dave Grabaskas
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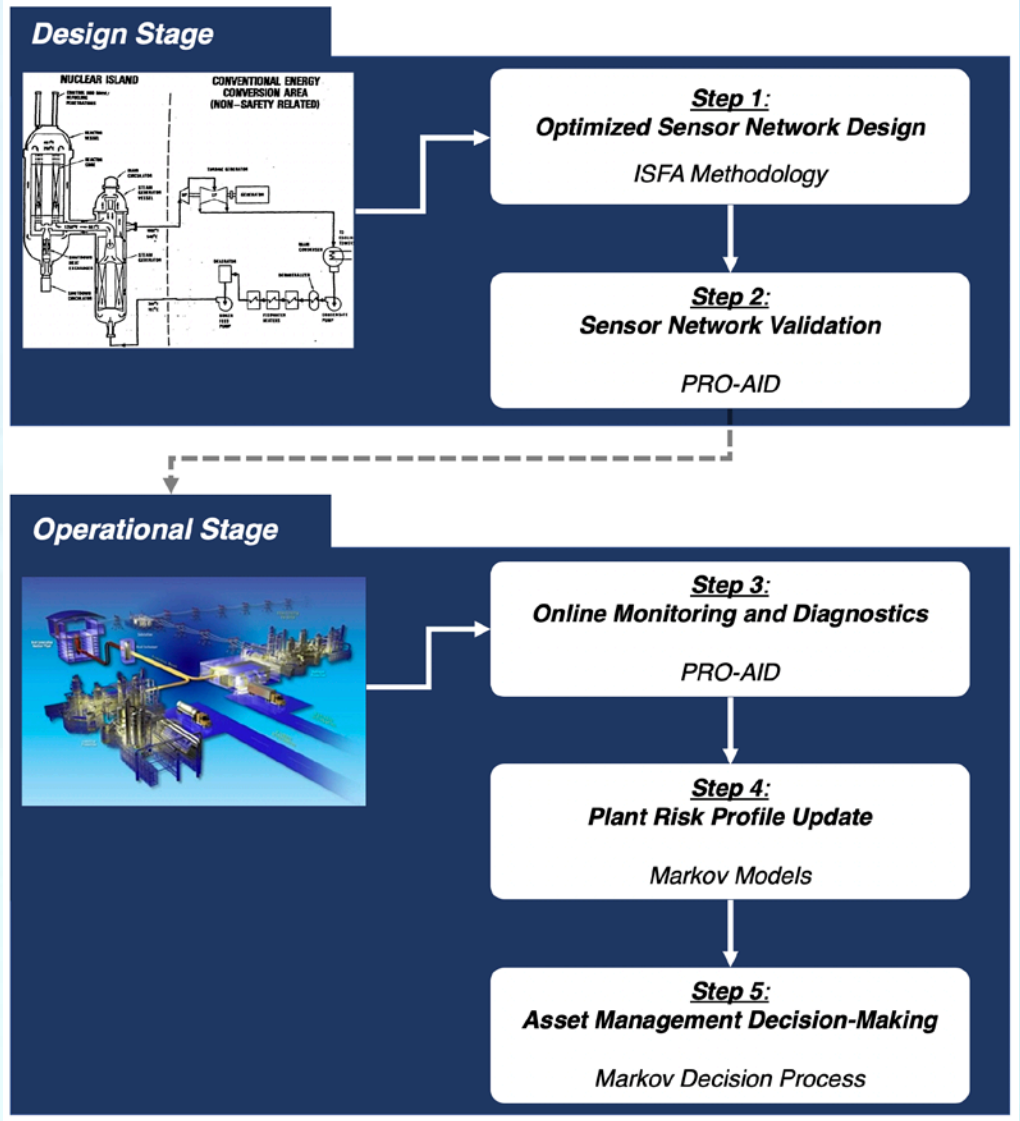
Pascal Brocheny
Many others…

Schedule: FY20 – early FY23

Project Overview

- Design Phase
  - Optimize the sensor network design based on a variety of criteria (cost, reliability, etc.)
  - Ensure the diagnosability of key faults and events, such as component degradation or sensor failure

- Operational Phase
  - Utilize online monitoring and diagnostic information to create a real-time model of the plant risk profile, including:
    - **Safety**: Probabilistic Risk Assessment (PRA)
    - **Economics**: Generation Risk Assessment (GRA)
  - The real-time risk profile facilitates intelligent asset-management decision-making through…
    - The identification and ranking of those components contributing to current or potential generation issues
    - The comparison of different operational plans and the predicted cost and return of each option



Project Overview

- Schedule:

FY20
- Establishment of overall process and flow
- Identification of new capabilities and methods
- Preliminary development of linking strategies

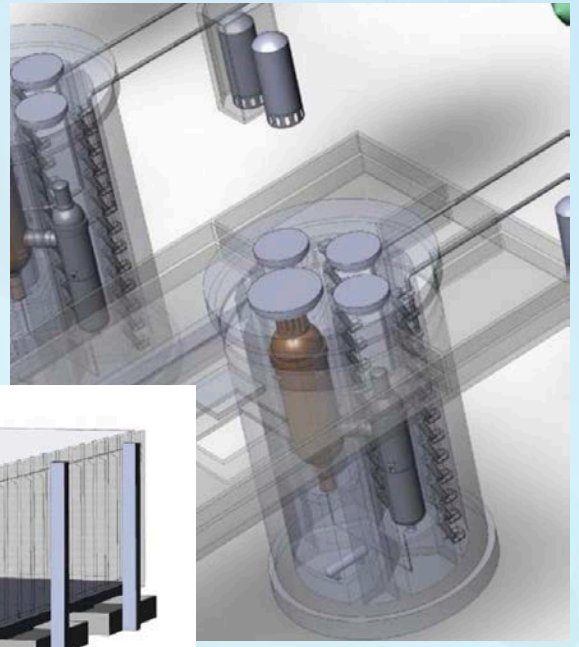
FY21
- Expansion of tool capabilities
- Continued development of linking strategies
- Selection of demonstration analysis

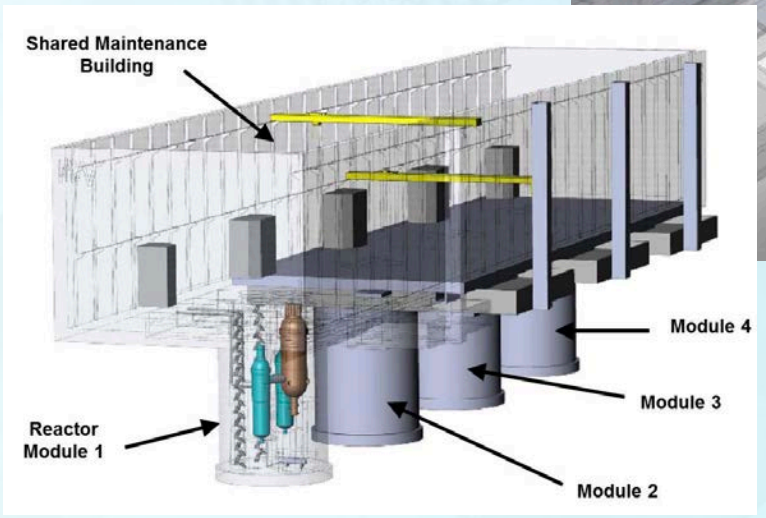
FY22
- Finalize method and tool development
- Complete demonstration analysis
- Publish findings and results

FY23

Technology Impact

- The central focus is economics of advanced reactor design and operation
- Maximizing the value of instrumentation and expanding the impact of monitoring data
- Taking tools and methods that have been developed by alternate DOE programs (ARPA-E, NEET, ART) and creating an integrated approach
- Working directly with industry to advance to demonstration and pursue commercialization





framatome

Results and Accomplishments

- Sensor Network Optimization
  - Integrated System Failure Analysis (ISFA) method
    - Developed by Ohio State University
    - Efficiently explores alternative sensor network designs
    - Expanding capabilities to facilitate new optimization acceptance criteria and allow sensor grading
  - New capabilities
    - Identified, defined, and instituted new optimization criteria
    - Identified, assessed, and selected optimization algorithm
    - Summarized in two completed M3 deliverables
  - Demonstration
    - Completed a demonstration of the approach

ISFA Optimization Criteria	
Observability	Uncertainty
Reliability	Risk Resistance
Cost	Failure Prognosis
Functionality	Integrability

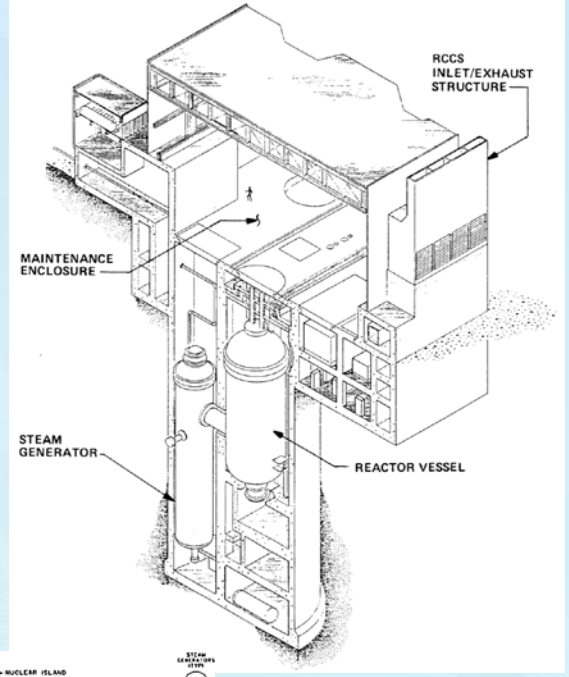
Evaluated Optimization Algorithms	
Evolutionary Algorithms	Genetic Algorithm
	NSGA
	NSGA-II
	Particle Swarm
	Distributed Wolf
	Microhabitat Frog-leaping
Greedy Algorithms	Greedy
	Hybrid Greedy
	Simulated Annealing

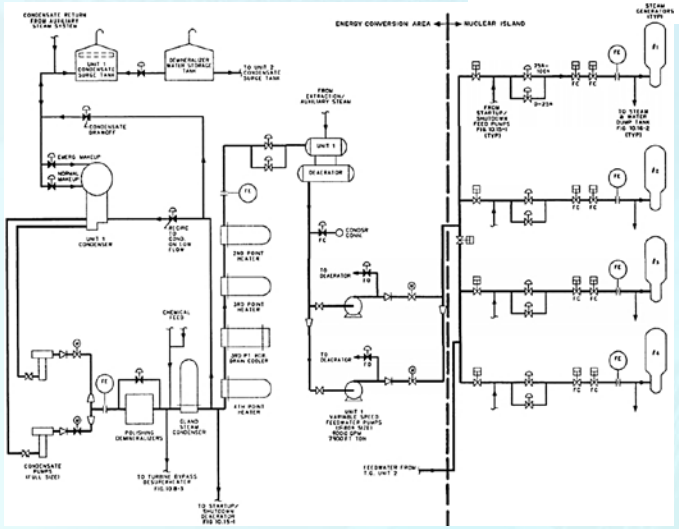
Results and Accomplishments

- Online Asset Management Decision-Making
  - Integrated Markov Decision Process Framework
    - As part of the project, an approach for online asset-management decision-making was developed that allows the direct incorporation of the following factors:
      - The estimated current status of all components/systems
      - The probability of components/systems failing or becoming degraded in the future
      - The cost of components/systems and all associated repair/replacement activities
      - The planned maintenance/repair activities
      - The revenue associated with different levels of plant operation
      - The regulatory acceptability of the plant for different operational states
  - Patent Process
    - The developed framework is currently undergoing preparations for patent submittal

Results and Accomplishments

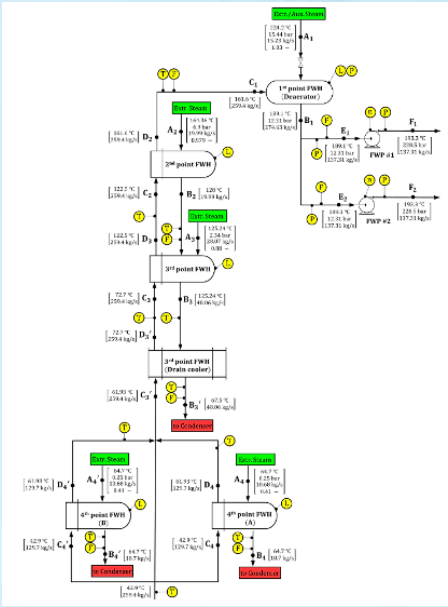
- Demonstration Analysis
  - **Goal:** To perform a comprehensive test and demonstration of the developed intelligent decision-making framework for a relevant advanced reactor design
  - Utilizing General Atomics MHTGR design, as it is sufficiently similar to the Framatome SC-HTGR design but without proprietary/ECI concerns
  - The MHTGR feedwater and condensate system was selected for the analysis, given the availability of component and system models, high importance to operational uptime, and interest of Framatome.



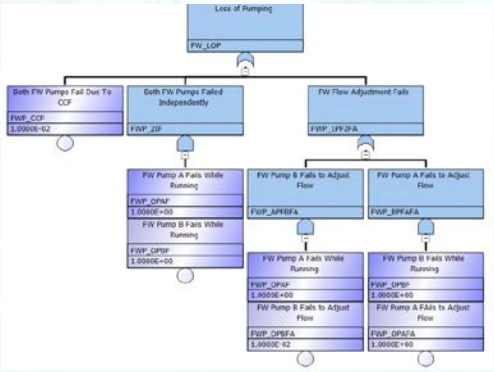


Results and Accomplishments

- Demonstration Analysis
  - Multiple development items necessary for the demonstration analysis:
    - Decomposition of the feedwater system (P&ID)
    - Plant surrogate development in Dymola
    - Probabilistic Risk Assessment (PRA) development
    - Generation Risk Assessment (GRA) development
    - Component modeling information (failure modes, failure rates, etc.)
    - Asset management information (repair/replacement costs, generation revenue, etc.)

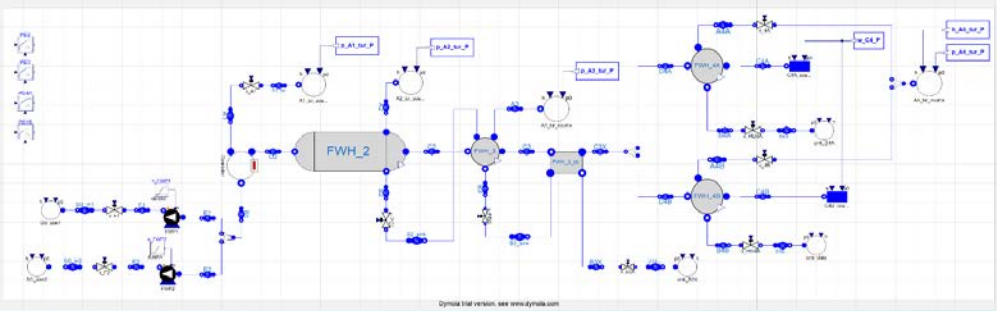


Developed Detailed P&ID



Loss of Feedwater Pump Fault Tree

Dymola FW System Surrogate



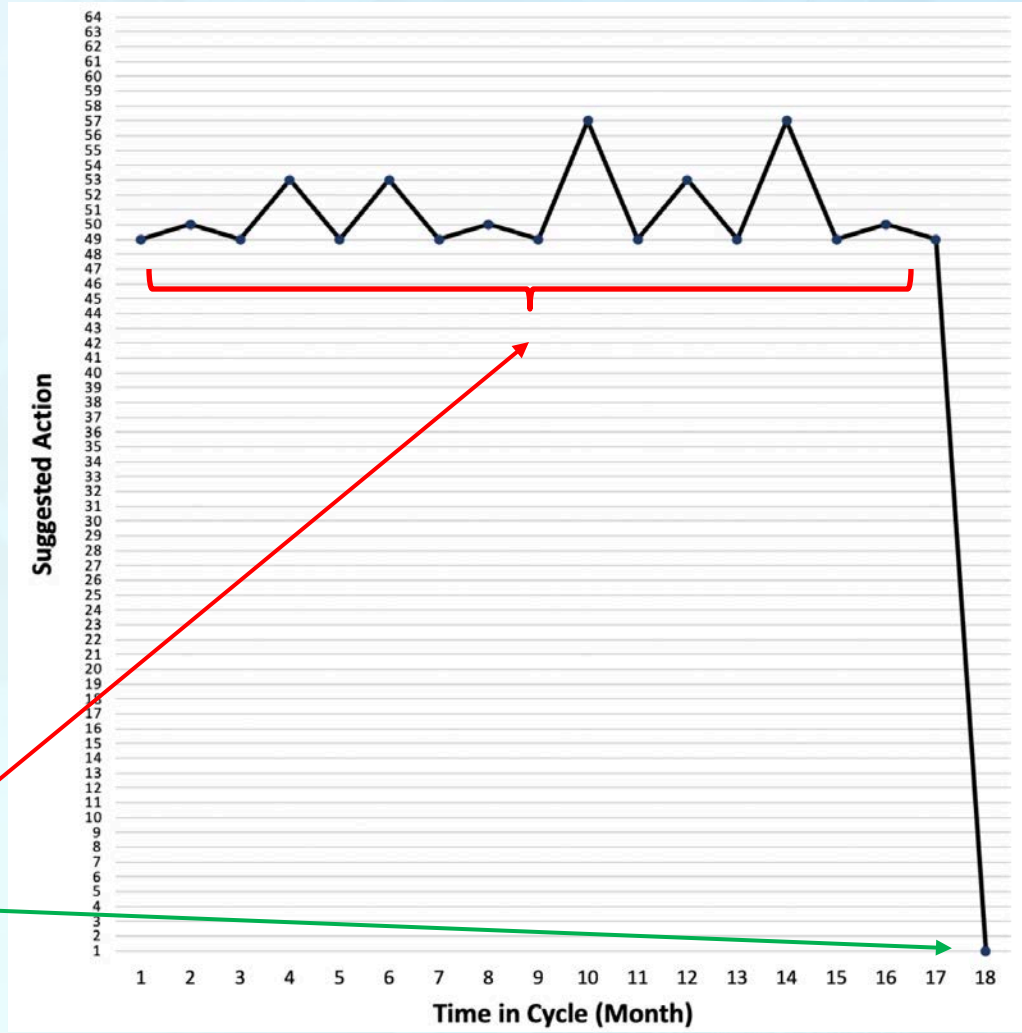
Results and Accomplishments

- Demonstration Analysis
  - The demonstration analysis focuses on the operational planning of the MHTGR feedwater system, although the performance of the entire plant is accounted for through the GRA and PRA
  - For the feedwater system, 5,625 system states are possible
  - 64 possible actions were considered at each time-step regarding the feedwater system, ranging from “do nothing and continue to operate” to “shutdown and repair all components”
  - The system states and possible actions result in a Markov Decision Process framework consisting of 2,025,000,000 transition probabilities
  - Even with >2 billion transition probabilities, the problem is still solvable in minutes on a desktop PC

A benefit of the developed approach is that it is scalable, while still considering whole-plant performance

Results and Accomplishments

- Demonstration Analysis
  - For the preliminary analysis, different operational cases were assessed to examine the performance of the analysis approach
  - The analysis compares the optimal decision at different points in the operational cycle
  - Further analyses increasing complexity
  - Investigating different visualization techniques for the results, given the complexity of the problem



Next Steps

- Refined Demonstration Analysis
  - Based on initial findings, the demonstration analysis is being refined in several areas to increase realism
- Time-to-Market (T2M) Report
  - Requested by Framatome, the report describes the necessary actions for commercialization and examines the business case
- Patent Process
  - Complete the patent process for the integrated Markov Decision Process approach for online asset-management decision-making
- Final Project Report
  - Project completion in early FY23

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Thank You