ADVANCED REACTORS AND THE NEED FOR ADVANCED CONTROL SYSTEMS

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INTELLIGENT, RISK-INFORMED ASSET-MANAGEMENT DECISION-MAKING AND MAINTENANCE OPTIMIZATION

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PROJECT BACKGROUND

Background:

DOE competitive NEET award (2019–2023)

Motivation:

Improve the economic competitiveness of advanced reactors through the optimization of cost and plant performance, which can be achieved by coupling online monitoring with intelligent asset-management decision-making

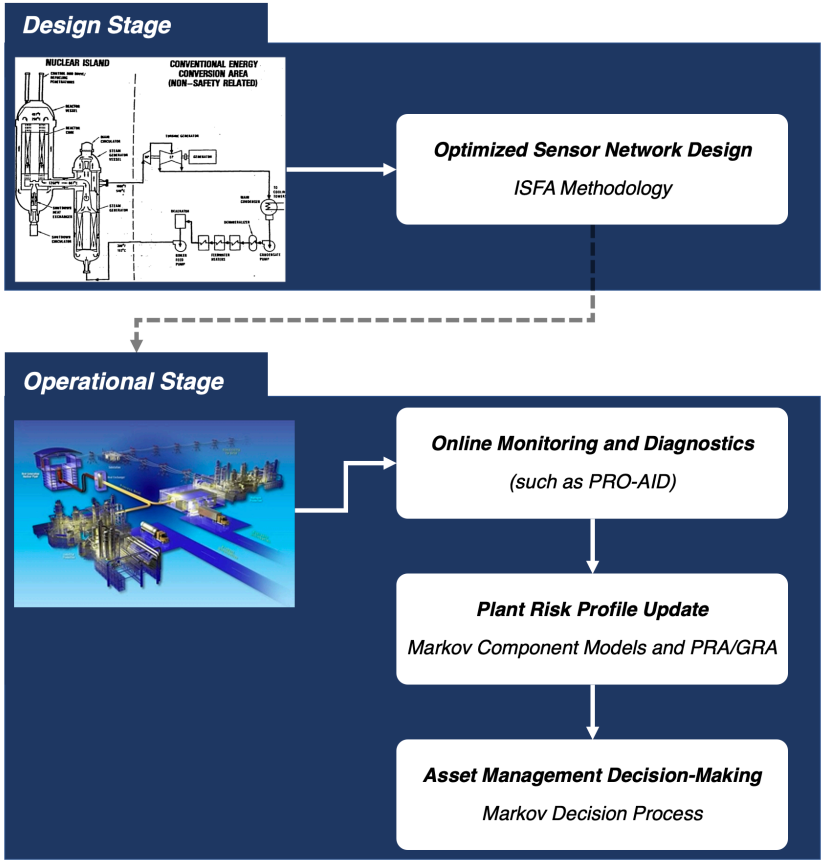
Participants:

Argonne NATIONAL LABORATORY

THE OHIO STATE UNIVERSITY

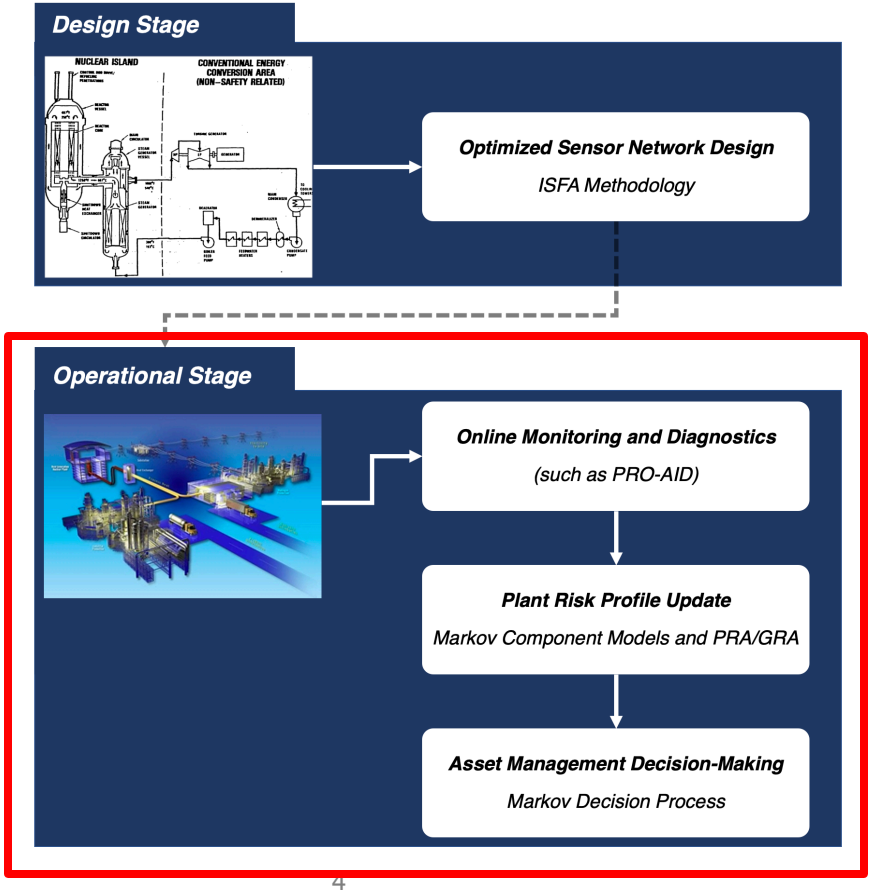
framatome

PROJECT FLOW DIAGRAM



PROJECT FLOW DIAGRAM

Focus of presentation



ASSET-MANAGEMENT DECISION-MAKING

Background:

Many of the factors associated with nuclear power plant operational costs are constrained by external factors (fuel costs, security requirements, etc.). Asset-management decision-making is one potential area for cost optimization that is generally within the control of plant operators

Challenges:

Optimization of asset-management decision-making requires the incorporation of a multitude of factors, including the following:

- Current system/component status
- Likelihood of future system/component degradation and failure
- Costs associated with maintenance and repair activities
- Generation revenue associated with different plant operational states
- Regulatory acceptability of plant operational

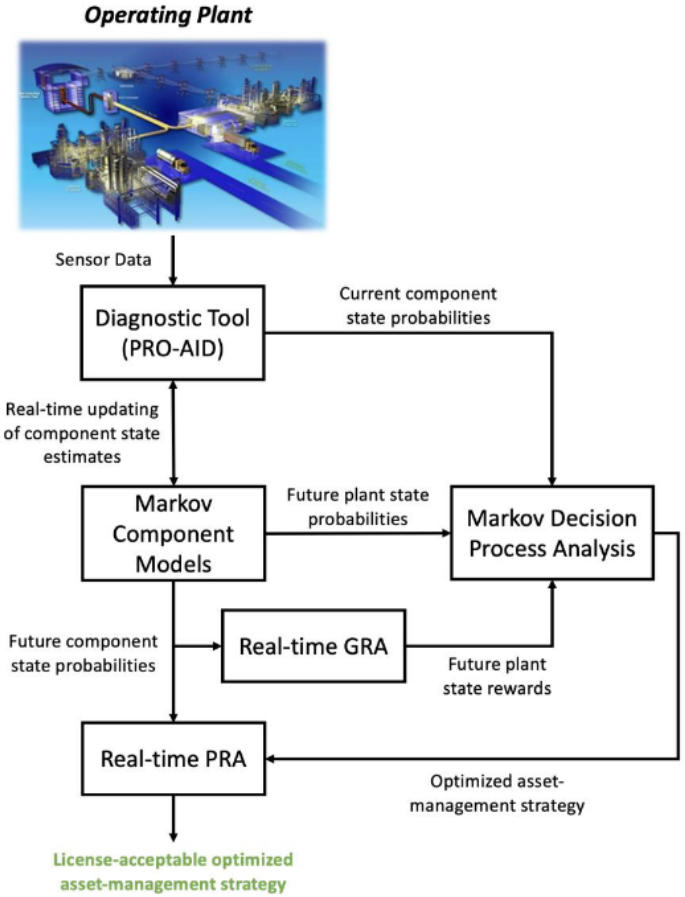
OBJECTIVES

Develop an asset-management decision-making approach that incorporates the relevant factors into an integrated analysis structure

Approach:

- Utilize online monitoring and diagnostics to provide real-time component status updates and create a real-time plant risk profile consisting of:
  - Generation risk assessment (GRA) assessing generation risk
  - Probabilistic risk assessment (PRA) assessing safety risk
- Utilize Markov component models to leverage historic component operating information and inform diagnostic software
- Use a Markov Decision Process (MDP) to incorporate the factors into a single analysis and rank possible action pathways based on their projected return

INTEGRATED APPROACH

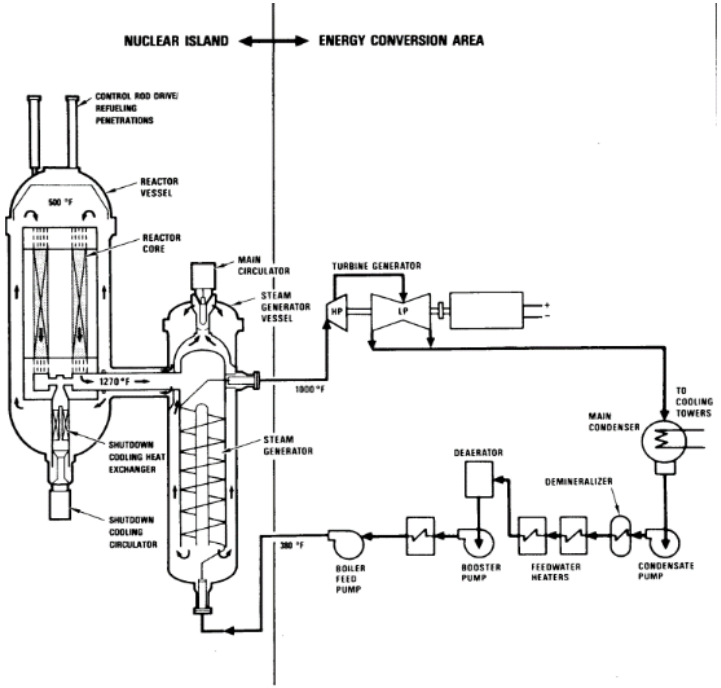


Limited technical detail provided due to pending patent application

DEMONSTRATION ANALYSIS: REACTOR

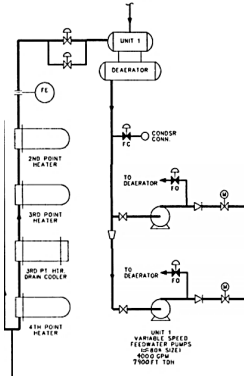
MHTGR Selection:

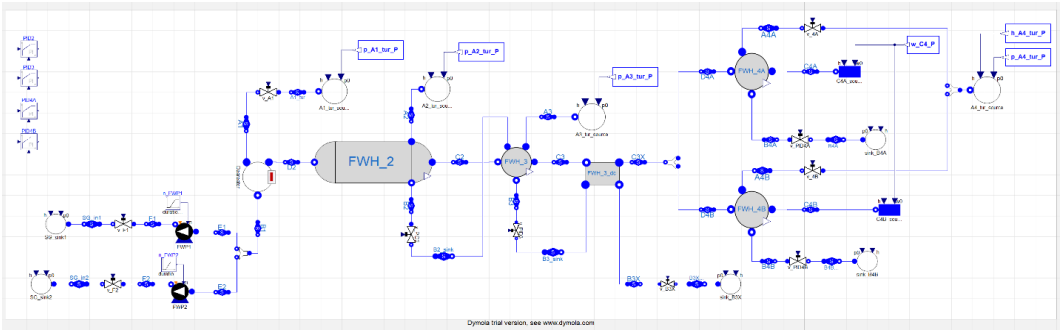
1. Reactor design is similar to the Framatome SC-HTGR design
2. Availability of detailed design and licensing documentation in the public domain (OSTI.gov)
3. The MHTGR licensing approach utilized a risk-informed performance-based method, similar to that of the Licensing Modernization Project (LMP)
4. The multi-module design permits additional operating modes

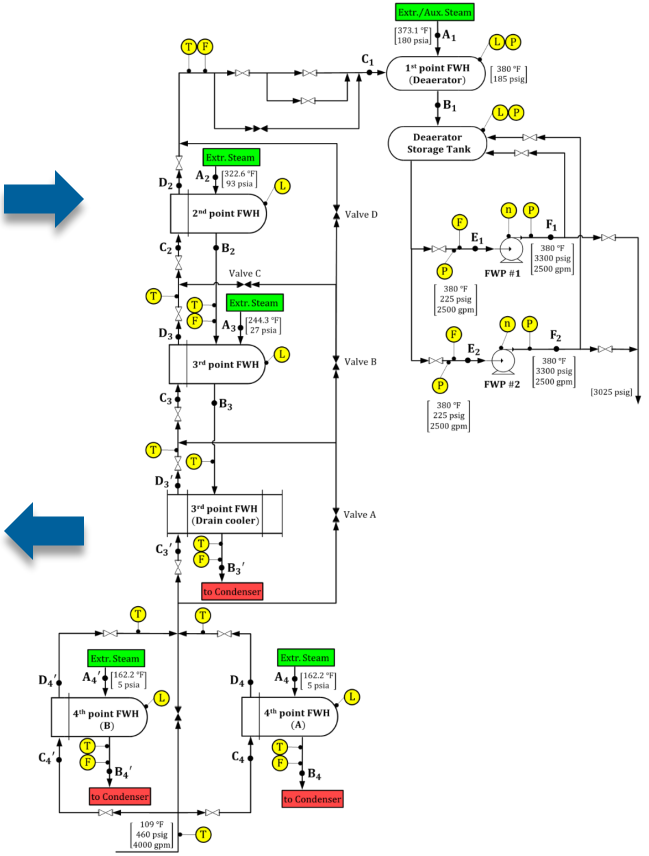


DEMONSTRATION ANALYSIS: SYSTEM/COMPONENTS

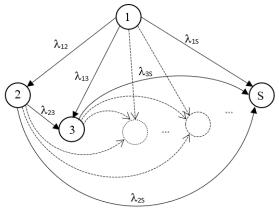
FW System Surrogate in Dymola



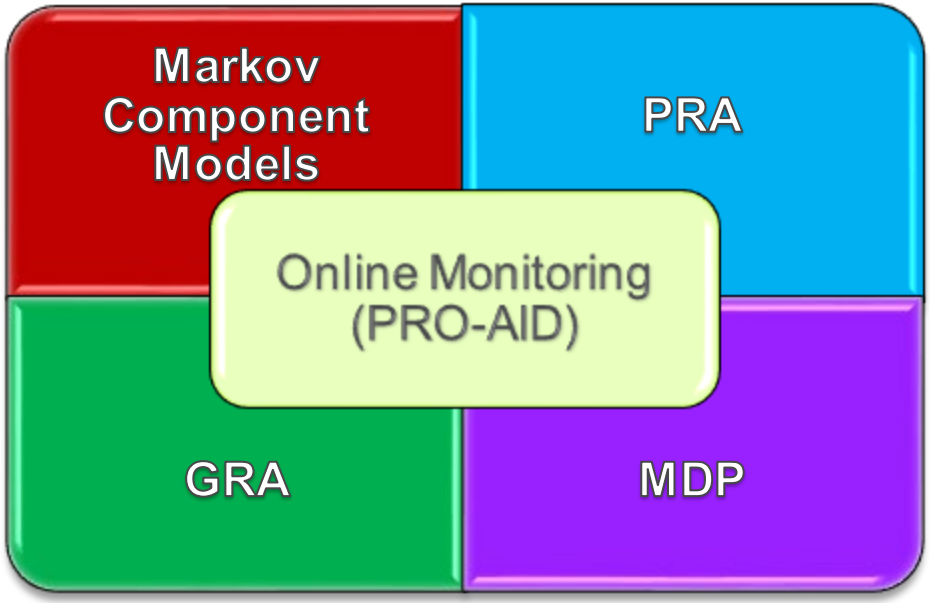


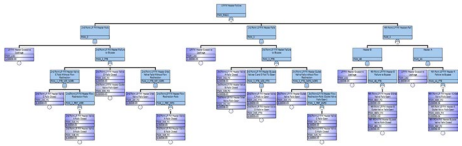


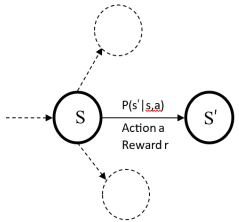
DEMONSTRATION ANALYSIS: MODULES



The approach is scalable!







DEMONSTRATION ANALYSIS: EXAMPLE RESULTS

Results:

- A variety of cases were assessed with different operating conditions (component states) and associated costs for repair/replacement activities
- The analysis was repeated for the same conditions but at different times in the operational cycle (assumed to be 18 months)
- The remaining time until the next plant shutdown influenced the recommended action

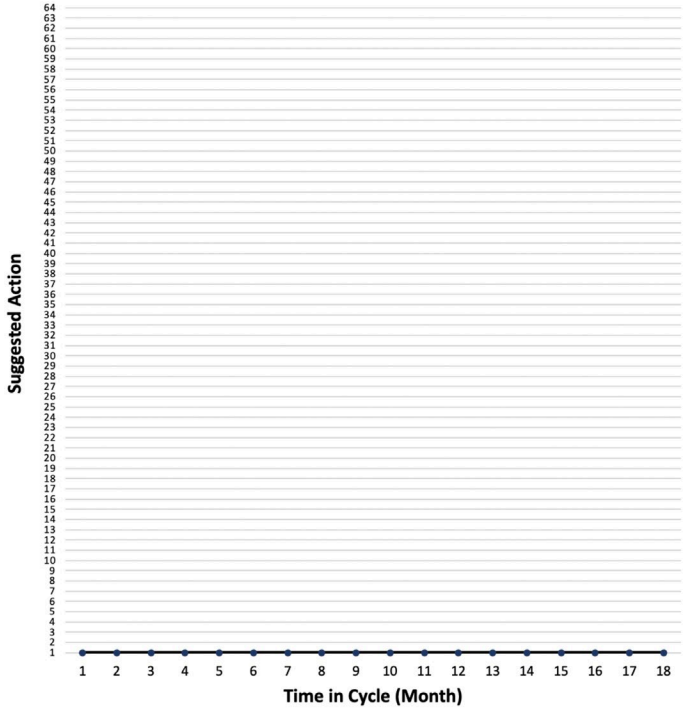
Examples:

- Initial examples examined fairly straightforward decision-making scenarios to validate methodology
- Later analyses examined increasingly complex scenarios

DEMONSTRATION ANALYSIS: EXAMPLE RESULTS

Example #1:

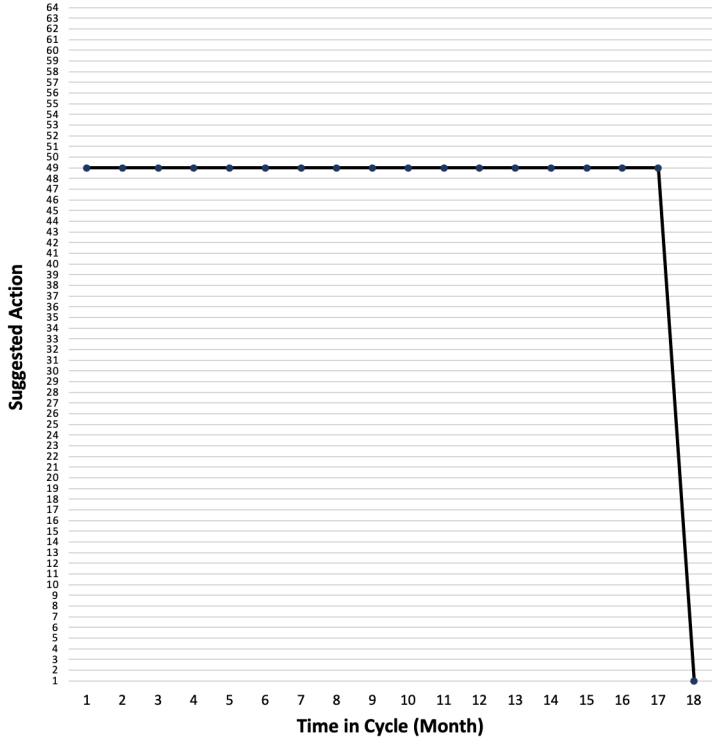
- 64 Possible actions
  - Ranging from “continue to operate at full power” to “shutdown and repair all FW components”
- The modeled FW components in Dymola have a high likelihood of being in a healthy state
- Approach recommends Action #1 “continue to operate at full power” at all times in cycle



DEMONSTRATION ANALYSIS: EXAMPLE RESULTS

Example #2:

- Potential FW pump degradation modeled in Dymola and diagnosed by PRO-AID
- Approach recommends Action #49 for most times in cycle, which involves reducing power and operating with a single FW pump, with repair of the other FW pump
- If the event occurs near the end of the cycle, the approach recommends operating at full power, as the time to the next shutdown is short, so there is little benefit in immediate repair



CONCLUSIONS

- The integrated MDP approach was able to perform an asset-management decision-making assessment of a system that was highly complex with over 2 billion possible transition pathways
- Although the focus of the analysis was on the FW system, the analysis allowed operational insights from the entire plant to be captured in the assessment (scalable approach)
- The program was able to calculate the result in a reasonable period of time (minutes on a desktop machine)
- The results for the initial analyses matched intuition for the simple cases assessed, providing a preliminary level of confidence in the solution scheme and overall framework

NEXT STEPS

- **Patent Completion**
  - A patent application is being prepared for the integrated MDP approach to asset-management decision-making, with upcoming patent submittal

- **Further Development Toward Commercialization**
  - A time-to-market (T2M) analysis was performed that identified several main tasks requiring completion before commercialization of the technical can be achieved.
  - These tasks include a demonstration of the cost savings potential of the approach utilizing a real-world example and further development of the approach regarding scalability and usability