Simulation-informed Dependency Treatment to Enhance Operational Flexibility, Avoid Production Loss, and Maintain Safety of Operating Plants and Advanced Reactors

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Pathway: Advanced Reactor Development Projects

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Project Objectives:

The objective of this project is to develop a technology-inclusive risk-informed solution to help the nuclear industry attain a realistic evaluation of dependency among protective systems and barriers and implement efficient preventive and mitigative strategies against dependency-induced issues. This objective is achieved by developing a first-of-its-kind methodology and computational tool to integrate modeling and simulation (M&S) data with risk-informed dependency analyses. The DOE NEAMS-funded software tools, including MOOSE and MOOSE-based applications, will be used as the central elements of the proposed computational framework to generate simulation-based dependency data. This project, for the first time, couples the MOOSE physics codes with a maintenance work process model to analyze the availability of protective systems by explicitly simulating interactions between physical degradation and maintenance activities. Additionally, this project will develop an automated computational interface between the MOOSE-based physics-maintenance simulation and plant PRA software. The computational tool will be equipped with essential features required for acceptable PRA such as common cause failure (CCF) treatment, M&S validation and uncertainty quantification, and Bayesian updating. The completion of this project will contribute toward enhancing operational flexibility, avoiding production loss, and maintaining safety of nuclear power plants (NPPs) in the U.S. through the extended use of advanced M&S in support of risk-informed activities for both operating plants and advanced reactors.

Project Description:

This project will be conducted in three phases.

- Phase I: Screen and select industry cases for operating plants and advanced reactors. This phase will identify and document screening criteria to select the component groups that require higher resolution and realism using the proposed dependency analysis approach. The developed screening criteria will then be applied for a Constellation plant and the Xe-100 design to select the industry cases that will be used as case studies.
- Phase II: Develop and validate simulation models for physical failure mechanisms and maintenance work processes. For the selected industry cases, a MOOSE-based simulation of physical failure mechanisms coupled

with a maintenance work process model will be developed. The validity of the simulation models will be evaluated by the Probabilistic Validation methodology that utilizes the epistemic uncertainties associated with input data, model structures, and numerical execution as a measure of validity.

- Phase III: Develop and implement a computational tool. To facilitate industry applications of the proposed methodology, a new computational tool will be developed to create an automated interface between the MOOSE-based physics-maintenance simulation and commercial PRA software. The computational tool will be applied to two case studies: a Constellation plant and the Xe-100 design.

The core of the methodology is the Simulation-informed, Probabilistic (SIP) approach developed by Co-PI Mohaghegh and her team at the University of Illinois at Urbana-Champaign (UIUC). The MOOSE and MOOSE-based applications (such as the Stochastic Tool Module) will be used to create a unified, coherent simulation environment for physical processes that may consist of multiple underlying physical processes. The computational tool for the PRA interface will be developed in compliance with Constellation's software quality assurance program and guidelines to ensure the readiness of the developed tool for industry applications.

Potential Impact of the Project:

For operating plants, this project will help the nuclear industry maximize the benefits of the risk-informed applications to improve O&M flexibilities through the more realistic CCF evaluation and reduction of an 'artificially' high sensitivity of the plant risk estimate to CCFs. This project is seen as a low-cost way to (i) significantly improve the Significance Determination Process (SDP) by supporting the submission of further information to pull back a greater-than-Green finding through the realistic CCF treatment; (ii) significantly improve the 10 CFR 50.69 process by stabilizing the risk importance criteria and enhancing justifications for the special treatment changes; and (iii) reduce the reoccurrence of CCF events by developing efficient prevention strategies to avoid negative impacts on plant safety, production, and O&M costs.

For advanced reactors, the adequacy of the dependency analysis can directly impact the acceptability of essential content of risk-informed licensing applications, for instance, the selection of licensing-basis events. The nature of advanced reactors, including the lack of operational data and the existence of new phenomena and systems that do not exist in operating plants, poses new challenges for dependency analysis. As of now, an organized investigation of dependency issues for advanced reactors has not yet been convened. In this project, the team will initiate a new line of research to obtain an in-depth understanding of dependency issues at advanced reactors using advanced M&S and propose a risk-informed solution to support the licensing process by providing a scientifically justifiable approach, for instance, justifications for realistic assumptions in licensing applications and thus avoid unnecessary safety features against dependency issues. This project offers a novel integration of the MOOSE and MOOSE-based applications with PRA, which will pave a way to significantly increase the opportunities for the DOE NEAMS-funded tools to be utilized in support of risk-informed programs for advanced reactors during various life cycle stages.

Project Deliverables:

- MOOSE-based physical simulation coupled with a maintenance work process model
- Computational tool to create an automated PRA interface with the MOOSE-based simulation
- Two case studies: (i) an operating Constellation plant and (ii) the Xe-100 design
- Two academic publications (conference papers or journal articles)
- Technical reports upon completion of each phase
- Quarterly Progress Reports and Final Technical Report