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Integrated Fire Probabilistic Risk Assessment (PRA) Modeling in Support of Operational Efficiency, Design and Innovative Risk-Informed Methodologies in the Nuclear Industry

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Pathway: Advanced Reactor Development Projects

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Abstract

Fire Probabilistic Risk Assessment (PRA) has been a challenging area for the safe operation and regulation of nuclear power plants (NPPs) due to the complex and dynamic progression of underlying physical failure mechanisms and their interaction with human actions affecting systems, structures, and components (SSCs). Since the introduction of risk-informed, performance-based fire protection approaches in 2005, the U.S. NRC and the nuclear industry have faced many obstacles in their efforts to increase realism in Fire PRAs (**Criterion b.1, 2nd bullet**). The NFPA-805 Fire PRA transition is highly resource-intensive, and the advantages of a risk-informed, performance-based approach have not yet been fully realized due to excessive conservatism in the current Fire PRA methodology. This research aims to improve the efficiency of risk-informed, performance-based fire protection for NPPs by advancing the current Fire PRA methodology using a risk-informed strategy originated by Co-PI Professor Zahra Mohaghegh from the University of Illinois at Urbana-Champaign (UIUC) (See IND FOA FY2019 Resume Mohaghegh ARD-19-17979.pdf). The three-phased strategy implemented in this research is as follows:

Phase I: Development of a streamlined approach to performing more efficient screening of Fire PRA scenarios for limiting the number of fire scenarios that need detailed Fire PRA modeling;

Phase II: Implementation of an Integrated PRA (I-PRA) methodological framework to reduce the excessive conservatism (i.e., increase the realism) in the current Fire PRA methodology by adding more explicitness and resolution to the underlying physics and human performance models;

Phase III: Conduct experimental validation of fire brigade performance models to justify their incorporation into I-PRA. Experiments will be conducted at the Illinois Fire Service Institute (IFSI) (See IND FOA FY2019 Capabilities ARD-19-17979.pdf) to run live scenarios of Fire Brigade response in an Auxiliary Building Switchgear compartment.

This research will result in new and more effective methodologies to provide data for decision-making while maintaining plant safety required by regulation. The fire brigade modeling tools that are validated through experimentation will be packaged into an Application Programming Interface (API) that can be integrated with fire simulation tools to run scenarios for Fire PRA. These tools will improve the use and implementation of existing risk-informed methodologies in the nuclear industry since a robust Fire PRA is one of the requirements for the implementation of risk-informed applications.

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Relaxing conservative assumptions by advancing the realism of physical and human performance modeling in the Fire PRA that currently exist in the Fire PRA methodologies will enhance the capabilities of domestic nuclear reactors. New reactor designs will benefit from the availability of quantitative tools to compare different design approaches and risk-significance of components, resulting in more realistic Fire PRA estimates (**Criterion b.1, 3rd bullet**). Risk-informed applications being considered for new reactors need robust and realistic Fire PRA models and will benefit from the scientific advancements being proposed in this project.

This project will develop new methodologies introduced above and apply them to the South Texas Project (STP) Fire PRA model in a demonstration of practical use. STP is known to have a robust PRA model and is a leader in the nuclear industry with respect to the amount and extent of currently implemented risk-informed applications, as evidenced by industry awards for piloted risk-informed applications, including NEI 'Best-of-the-best' and 'top industry practice' awards (See IND FOA FY2019 Past Performance ARD-19-17979.pdf). STP and UIUC have proven their ability to develop practical, scientifically rigorous, and academically defensible research outcomes through collaborations that result in high-impact risk-and-cost savings for the nuclear industry (See IND FOA FY2019 Benefit of Collaboration ARD-19-17979.pdf and IND FOA FY2019 Capabilities ARD-19-17979.pdf). UIUC and the IFSI will perform a benchmark study with STP to establish I-PRA methodologies and experimental validation for fire brigade performance that will result in methodologies that can help to improve Fire PRA estimations across the industry. These tools will help to improve the ease of commercialization for advanced reactors by supplying simulation methods for scenarios where operational performance data is unavailable and will help utilities to reduce unnecessary costs of excessive fire protection requirements caused by existing and overly conservative Fire PRA practices.

This proposed project is well aligned with the goals of the DOE Funding Opportunity Announcement (FOA). This project focuses on a longstanding gap[1]: the nuclear industry's need for effective, efficient, and equitable Fire PRA technologies that can be applied by industry to reduce the burden of overly conservative fire risk estimates in operations and design (**Criterion b.1, 2nd bullet**). STP will serve as the pilot plant for implementing the advanced methodologies proposed in this work, working with UIUC and the IFSI to demonstrate how better modeling and simulation of fire events at NPPs can reflect operational realism, resulting in cost savings and risk reductions. STP will translate their experience of implementing these methodologies into new guidance for the industry and document their capabilities for improved operational efficiency, decision making, and innovation by adopting advanced Fire PRA methodologies in risk-informed applications and decision-making tools. This project can also lead to performance and economic improvements at other NPPs that have been seeking NRC approval for their submittals of risk-informed applications but have not been successful due to the conservatism that is currently built into their Fire PRA models. Further, these approaches can help to ease commercialization for new reactor designs by supporting scientific justification for fire protection design criteria in license applications.

Deliverables of this project will include: Documented Procedures for Site-Specific Application of Fire RoverD, Gap Analysis of STP PRA model with Phase I Methodology Results, Conference and Journal Papers on Phase 2 results, Experimental Procedures and Guidelines for Nuclear Power Plant Fire Brigades, Fire Brigade Human Performance Dataset, Gap Analysis and Bayesian Analysis of Experimental Results, Quarterly Progress Reports, and a Final Project Report.

[1] See "Fire PRA Maturity and Realism: A Technical Evaluation" by N. Siu, K. Coyne, and N. Melly, Office of Nuclear Regulatory Research, U.S. NRC, 2016.