U.S. Department of Energy

The Application of Dynamic PRA to Revolutionize the PRA Model Development during the Design, Licensing, and Maintenance Activities of Current LWRs and Advanced Reactors

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Funding Opportunity: Distinguished Early Career Program

ABSTRACT:

Ensuring safe, secure, and cost-competitive operations, as well as reliable energy production, storage, and delivery infrastructure are top priorities for the global energy industry. Defense-in-depth, safety margins, and probabilistic risk assessment (PRA) have contributed to the excellent safety record of the nuclear industry. As such, nuclear power plants are among the safest and most secure industrial facilities in the world. Nevertheless, the serious nuclear accidents to date (e.g., SL-1 1961, Three Mile Island 1979, Chernobyl 1986, and Fukushima Daiichi 2011), important incidents (e.g., Browns Ferry 1975, Salem 1983, LaSalle 1988, Vandellos 1989, Browns Ferry 1975, Blayais 1999, Duane Arnold 2020), numerous U.S. Nuclear Regulatory Commission's licensee event reports, or cyber-security threats to critical infrastructure have illustrated the ongoing importance of the need for vigilance and total commitment to enhancing nuclear reliability, safety, and security.

After the breakthrough of the Reactor Safety Study from the early 70s and the watershed industry-led PRAs from the 80s, including Oconee, Zion, Indian Point, and Seabrook that radically changed the way we evaluate the safety of nuclear reactors by embracing uncertainty, it is about time we take the PRA model development into the 21st century to address the completeness problem. While PRA provides the probabilities and combinations of component-level failures that can cause system failure, how well we cover the space of possible event sequences is still unclear. This lack of understanding creates distrust in the current PRA models and insights leading to overly conservative designs and safety margins. A solution to the completeness problem is long overdue, and it is critical to the development of realistic event sequences with dynamic behaviors to the design and maintenance of cost-competitive nuclear reactors. Fortunately, what has been mostly hypothesized on theoretical grounds, it is now within our grasp through dynamic PRA techniques to model realistic plant responses in which deterministic transient models are supported by time-dependent failure models for realistic success criteria.

The main objective of the proposed work is to demonstrate the way dynamic PRA insights can be used to rethink how we can address the completeness problem of the PRA models during the design, licensing, and maintenance activities of current LWRs and advanced reactors by including dynamics observed during actual operating events. To achieve this, we will first use deep learning based natural language processing trained models to extract the event sequences with the dynamics observed during actual operational events from incident and accident reports of research and commercial reactors. The obtained classes of realistic dynamic behaviors and the level of treatment of such dynamics needed in PRAs will be used to design and implement an open-source, web-based, technology-inclusive, full-scope dynamic PRA platform. Finally, we will develop the first guidance on how to use the developed dynamic PRA platform to rethink the development and updating of PRA models for current LWRs and advanced reactors. The guidance will be piloted on a generic pressurized water reactor (PWR) and a generic small modular reactor (SMR) based on existing high temperature gas reactor (HTGR) technology. This work leverages half a century of PRA practice and three decades of research efforts in dynamic PRA.