A Strategic Approach for the Evaluation of Risks and Costs Reduction for Enhanced Resilient Nuclear Power Plant Systems

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Risk-Informed Systems Analysis Pathway

A number of recent initiatives in the nuclear industry aim to enhance the safety and improve the economic competiveness of existing nuclear power plants. These initiatives include efforts on developing accident tolerant fuel [1], a Diverse and Flexible Coping Strategy (FLEX) [2] for a beyond design basis event, and an industry-wide initiative entitled, "Delivering the Nuclear Promise: Advancing Safety, Reliability, and Economic Performance" [3]. The collective changes resulting from these initiatives aggregately contribute to nuclear power plants that are more efficient and resilient to external events.

Accident tolerant fuel research and development is ongoing; the main attributes of accident tolerant fuel include improved fuel and cladding properties, lower clad reaction with steam, slower hydrogen generation rate, better fission product retention, and enhanced fuel cladding interactions. These attributes should lead to higher melting temperature of fuel and cladding, longer time windows (i.e., coping time) for operator and safety system mitigating actions, and enhanced human reliability of critical recovery actions during abnormal events or severe accidents. Longer coping time permits effective utilization of the FLEX equipment and accompanying mitigating strategies during postulated events.

To fully realize the benefits of potential safety enhancements, methods for assessing the benefits to risk and cost reduction need to be developed and demonstrated. Methods and approaches being developed by the Risk-Informed Systems Analysis pathway support the application of new tools to perform comprehensive risk-informed evaluations of design changes at the plant system and component level in an integrated manner to estimate proposed operational and physical plant modifications on safety and margins. This entails developing an Integrated Risk Evaluation Model, as illustrated in Figure 6, by combining probabilistic risk assessment methods with best estimate plus uncertainty methods. Probabilistic risk assessment methods evaluate scenarios in order to determine accident sequences that include failure of systems, structures, and components given a set of prescribed initiating events. Probabilistic risk assessment methods not only estimate risk metrics, such as core damage frequency, but also determine what the most probable accident sequences are and the components that contribute the most to overall plant risk. Best estimate plus uncertainty methods employ multi-physics analysis tools in order to assure that plant safety systems can prevent core damage conditions for a given set of accident conditions. The results of the integrated risk evaluation approach will be a qualitative characterization of systems, structures, and components risk reductions for increasingly longer coping time, as well as the associated economic and regulatory benefits.

With the selection of candidate accident tolerant fuel and enhanced resilient nuclear power plant systems (e.g., FLEX, new passive cooling systems, etc.), the Integrated Risk Evaluation Model will be used to perform detailed probabilistic risk assessment/best estimate plus uncertainty analyses. Specifically, the following analysis steps will be carried out:

1. Identify a set of accident sequences for both pressurized and boiling water reactors that might be mitigated by accident tolerant fuel/enhanced resilient nuclear power plant systems. The candidate scenarios include short and long-term station blackout, loss-of-coolant, loss of feedwater, anticipated transients without scram, steam generator tube rupture, turbine load mismatch, etc.
2. Identify new phenomena, e.g. core structure might fail before fuel fails, that need to be considered with the adoption of accident tolerant fuel/enhanced resilient nuclear power plant systems. These phenomena may bring changes to the plant responses and accident analyses.

3. Perform best estimate plus uncertainty calculations using fully coupled models by simulating the core/fuel/cladding and plant/system interactions in order to determine plant integrity for the candidate accident tolerant fuel/enhanced resilient nuclear power plant systems.
4. Conduct detailed probabilistic risk assessment by performing scenario-specific accident analyses. The analyses will reflect the plant responses incuding the stochastic behavior of applicable systems, structures, components, and human actions. The evaluation will investigate risk analysis perturbations, including potential changes in system success criteria, human actions, and component performance. These perturbations will be characterized according to their risk reduction in order to find beneficial plant changes.

Once the possible positive changes in risk and safety margins are identified, the Integrated Risk Evaluation Model can be used in high value risk-informed decision-making applications, both in operational and regulatory applications.

The operational applications include: enhanced fuel performance and core design efficiency through increased enrichment, burnup extension, fuel cycle length extension and load following; risk-informed surveillance test interval; risk-informed technical specification completion times; risk-informed emergency planning zone, and 10CFR 50.69 considerations to better understand potential changes that are possible for the specific systems, structures, and components of interest. Application of 10CFR 50.69 allows plant equipment to be recategorized based on its safety designation (i.e., safety-related or non-safety-related) and its risk significance (i.e., risk-significant or non-risk-significant). For example, safety-related equipment could be recategorized as safety-related, but non-risk-significant, due to the reduction of the risk significance of this equipment with increased coping time and increased availability of FLEX mitigating equipment/strategies. This recategorization implies potential cost savings on the production, maintenance, surveillance, and administration of plant equipment designated as safety-related.

The regulatory applications include: the justification for continued operation; limiting condition for operation; and component design bases inspection processes. The risk significance reduction of the current plant equipment could also benefit nuclear power plant owners and operators in complying with the U.S. Nuclear Regulatory Commission Reactor Oversight Process including Significance Determination Process and Mitigating Systems Performance Index. All of the aforementioned risk-informed applications can be translated to direct economic benefits with the continuation of plant operation and the reduction of operating, oversight, maintenance, and administration costs.

References:

1. Shannon Bragg-Sitton, "Development of advanced accident tolerant fuels for commercial LWRs," Nuclear News, March 2014.
2. https://www.nrc.gov/docs/ML1524/ML15244B006.pdf
3. https://www.nei.org/Issues-Policy/Delivering-the-Nuclear-Promise

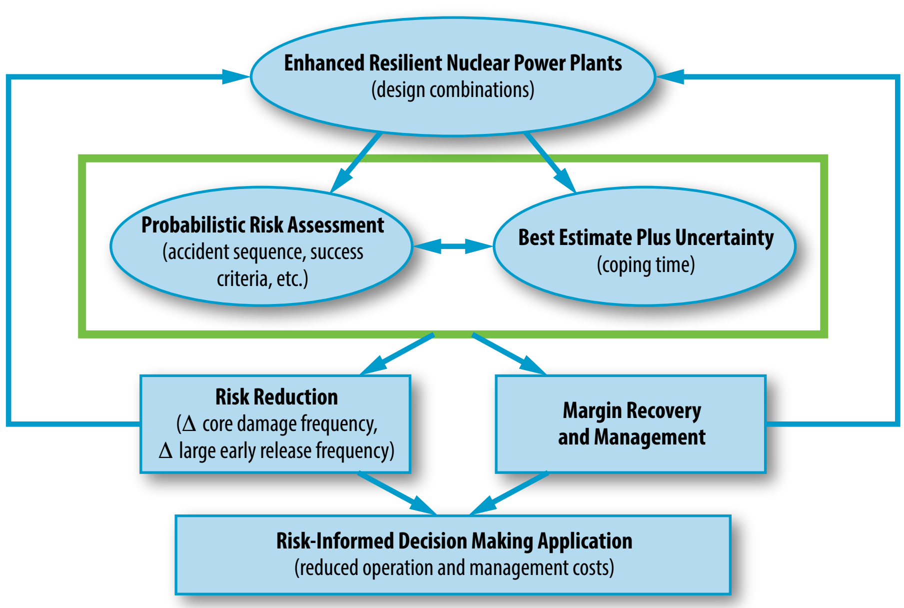

Figure 6. Schematic illustration of the Integrated Risk Evaluation Model for the enhanced resilient nuclear power plant.