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Probabilistic Risk Assessment

Background

The Nuclear Regulatory Commission's responsibilities include ensuring U.S. nuclear power plants and other licensed facilities operate with minimal risk to public health and safety. The NRC uses the probabilistic risk assessment – often called PRA – techniques to examine a complex system's potential risk and identify what problems could have the most impact on public health and safety.

The NRC lists technical and regulatory requirements on plant design and operations in Title 10 of the Code of Federal Regulations (10 CFR). The requirements are often written in terms of engineering practices that add "safety margins" and "defense-in-depth" during plant design, construction, and operation. PRAs can evaluate the effectiveness of safety margins and defense-in-depth, and in some cases improve them.

Risk

Risk comes from three factors:

- What can go wrong?
- How often can something go wrong (how likely is it?)?
- What happens if it goes wrong (consequence)?

We reduce risk by making a bad event less likely or by reducing its consequences. The NRC and the nuclear industry use PRA as one way to evaluate and reduce overall risk.

Risk Assessment Methods

Performing a PRA requires several steps:

Specify the **hazard** – the outcome(s) to be prevented or reduced. For nuclear power plants, the focus is reducing the chance of damaging the fuel in the reactor core.

Identify **initiating events (i.e, what can go wrong)?** – things that could possibly cause the hazard (e.g., breaking a pipe carrying water to cool the core).
Estimate the **frequency (i.e., how likely is it)?** of each initiating event by answering questions such as, "How often do we expect a pipe of this size to break?"
What happens if the hazard happens (i.e., what are the consequences)?

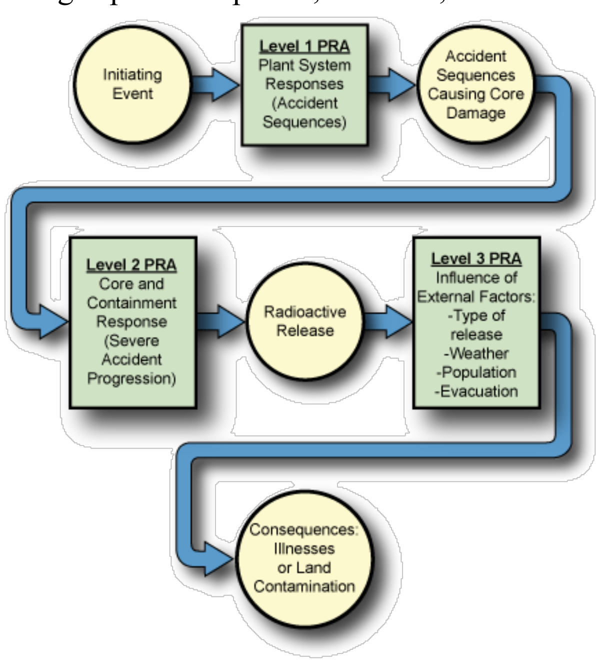
For each initiating event, risk analysts identify combination of failures (e.g., pump failure and valve failure) that lead to a specific outcome. Analysts then calculate the likelihood of each combination of events and add up the probabilities of all the sequences that lead to the same outcome. The likelihood of the outcome equals the sequence probabilities multiplied by the frequency of the initiating event(s).

PRA uses several specific techniques to accomplish this analysis:

- *Event trees* model the plant response to each initiating event.
- *Fault trees* model plant systems in detail so that analysts can identify the combinations of failures that disable an overall system. The fault tree logic also calculates the overall failure probability. Analysts pay particular attention to problems that can fail more than one component at the same time.
- *Human reliability analysis* evaluates human errors that are important to the outcome of an event. Analysts assess the probability of human mistakes based on factors such as training, procedures, and expected conditions during an event.
- *Monte Carlo methods* are a variety of computer modeling that are used, if necessary, to help account for uncertain parts of the analysis. These methods consider variations in each factor of the analysis, imperfect knowledge and the many possible ways the factors can interact.

Types of Risk Assessments

Developing even the most basic PRA model requires a lot of effort. Modern computers have enough speed and power, however, so that analysts use, re-use, and refine PRA models to address many questions.



Nuclear power plant PRAs deal with “internal events” – those that start inside the power plant or the electric system it serves – and “external events” such as earthquakes and hurricanes. PRAs can also address unique situations such as spent nuclear fuel storage cask design or the geology of a potential site for permanently storing high-level radioactive waste.

Nuclear power industry PRAs fall into three levels:

- A Level 1 PRA estimates how often a reactor core could be damaged. It starts with well-understood conditions, usually a reactor operating at full power. A Level 1 PRA also models a reactor's protective systems. These systems are so well understood that a Level 1 PRA has relatively small uncertainties.

- A Level 2 PRA estimates how much radioactive material reaches the environment, and how quickly the material could be released. Level 2 PRAs are less precise, due to more uncertainties such as how much water or steam escapes the reactor systems (and how violently), as well as variations in how the reactor's containment structure responds.

- A Level 3 PRA estimates the health effects and economic losses that might result if radioactive material reaches the environment. Level 3 PRAs have the largest uncertainties, since they include highly variable factors such as wind speed and direction.

Risk Assessment Results

PRA results are complex and can't be reduced to a single number. Instead, PRAs provide a spectrum of possible outcomes. The frequency for each outcome is provided as a *distribution* of values. PRAs help understand how much larger or smaller an outcome's actual risks might be.

PRA results are uncertain because reality is more complex than any computer model, because analysts have imperfect information, and partly because of chance. Analysts and regulators maintain confidence that PRAs help achieve adequate safety in one of two ways:

1.Imposing strict enough safety margin and defense-in-depth to account for the uncertainties in estimated risks; or

2. Increasing the PRA's certainty so that a smaller margin can provide the same (or better) confidence of safety.

Analysts reduce uncertainty by a) enhancing their models to more accurately reflect the real world; b) incorporating research results to improve the physical processes they model; or c) collecting additional data to improve model precision. The NRC does all of these.

NRC Uses of PRA

The NRC first developed nuclear power plant PRAs in the 1970s. Since then the agency has refined its methods and developed new risk insights. The NRC combines these insights with traditional engineering methods to make regulatory decisions about power plants, medical uses of nuclear materials, and the handling of nuclear waste. This “risk-informed” approach to regulation includes:

- Plants use PRA for integrated plant evaluations that discover and correct subtle vulnerabilities, resulting in significant improvements to reactor safety.
- Inspections use PRA insights to focus on plant systems, operations and human performance that are most important to safety.
- The Reactor Oversight Program’s significance determination process uses plant-specific PRA models to assess the safety impact when a piece of equipment fails or is taken out of service for maintenance. The NRC increases its inspection and oversight as nuclear plant problems increase in risk importance.
- The NRC often uses PRA to confirm that new or revised rules are rigorous enough to cover uncertainties – and to justify new requirements.
- The NRC has used special PRAs to assess issues such as spent fuel storage cask safety.

The nuclear industry uses PRA to:

- Enhance existing plant designs by reducing vulnerabilities.
- Reduce risk when multiple systems are being maintained.
- Focus resources on the most safety-significant systems and components, through risk-informed technical specifications, risk-informed in-service inspection programs, and risk-informed categorization of structures, systems, and components.
- Analyze and enhance new reactor designs before asking the NRC to certify them.

The NRC expects wider PRA use should result in more predictable and timely agency actions.

The NRC's website has a more detailed discussion on PRA.

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