U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

BACKGROUNDER
Office of Public Affairs
301.415.8200
www.nrc.gov ■ opa.resource@nrc.gov

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 science of probabilistic risk assessment (PRA) to examine a complex system's potential risk and identify what problems could have the most impact on safety.

The NRC lists technical 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" during plant design, construction and operation. PRA can better define these margins and in some cases information from the analysis can suggest improvements.

Risk

Risk comes from two factors:

- How often can something go wrong?
- What happens if it goes wrong?

The NRC's regulation, oversight, and enforcement reduces risk by making a bad event and its corresponding effects less likely. The NRC and the nuclear industry use PRA as one way to evaluate and reduce the overall risk to the public and environment.

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 and potentially release radioactive material to the environment.
- Identify a spectrum of **initiating events** – things that could possibly cause the hazard (e.g., breaking a pipe carrying water to cool the core).
- Estimate the **frequency** of each initiating event by answering questions such as, "How often do we expect a pipe of this size to break?"

Risk analysts assume each initiating event occurs and then given the response to that event, realistically identify each combination of failures (e.g., pump failure and valve failure), or "sequence," that leads to a specific outcome (e.g. core damage). Analysts then calculate the likelihood of all the sequences that lead to the same outcome. The likelihood of the outcome is the sum of the sequence frequencies.

PRA uses several specific techniques to accomplish this analysis:

- *Event trees* model the plant response to each initiating event in terms of plant system combinations.
- *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. Fault tree logic takes into account engineering calculations in determining how plant systems, components, structures, and operators interact.
- *Human reliability analysis* evaluates human errors that are important to the outcome of an event. Analysts assess the probability of human mistakes in light of factors such as training, procedures, and expected conditions during an event.

Analysts use several computer modeling methods that consider variations in the data when estimating failure probabilities and how they interact together. Such methods include *Monte Carlo* and *Latin Hypercube Sampling*.

Types of Risk Assessments

Developing even the most basic PRA model requires a great deal of effort. Fortunately, modern computers and software have evolved to provide the necessary speed and power giving analysts the opportunity to 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, floods, and hurricanes. PRAs can also address unique situations such as spent nuclear fuel storage cask design or the geology of a potential site for permanent storage of high-level radioactive waste.

Nuclear power industry PRAs fall into three levels:

- A Level 1 PRA estimates the likelihood that a reactor core could be damaged. It starts with well-understood conditions, usually a reactor operating at full power. A Level 1 PRA models all of a reactor's protective and accident mitigation systems. These systems are so well understood that a Level 1 PRA has relatively small uncertainties.
- A Level 2 PRA assumes core damage and then estimates how much radioactive material reaches the environment, and how quickly the material could be released. Level 2 PRAs are less precise, due to a larger uncertainty associated with how much water or steam escapes the reactor or coolant pipes (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 are the least precise, 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 uncertainty exists because reality is more complex than any computer model, because analysts have incomplete information, and partly because of chance. Analysts and regulators maintain confidence that PRAs help achieve adequate safety in one of two ways:

- Imposing strict enough safety margin to account for the uncertainty in estimating risk; or
- Increasing the PRA's modeling 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 developed its first nuclear power plant PRAs in the 1970s and ever since 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 using PRA for integrated plant evaluations that discover and correct subtle vulnerabilities, resulting in significant improvements to reactor safety.
- Inspections have used 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 PRA models of each plant to assess the safety impact when mistakes occur or plant performance declines. The NRC increases its inspection and oversight as nuclear plant problems increase in risk importance.
- PRA can be used to comply with performance-based maintenance and fire protection regulations.
- 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 while a plant operates.
- Enhance risk-informed technical specifications and risk-informed in-service inspection programs to focus resources on the most safety-significant systems and components.
- Analyze and enhance new reactor designs before asking the NRC to certify them.

The NRC expects PRA use will continue growing, which should further enhance the agency's predictable and timely resolution of issues.

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