U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

FACT SHEET

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Probabilistic Risk Assessment

Background

One of the Nuclear Regulatory Commission's key responsibilities is to ensure the operation of nuclear power plants and other NRC-licensed facilities present no undue risk to public health and safety. The agency does this by applying and enforcing a set of technical requirements on plant design and operations, described in Title 10 of the Code of Federal Regulations (10 CFR). Generally, these are written in terms of traditional engineering practices such as "safety margins" in design, construction, and operations. Probabilistic risk assessment (PRA) systematically looks at how the pieces of a complex system work together to ensure safety. PRA allows analysts to quantify risk and identify what could have the most impact on safety.

Risk

Risk is determined by two factors:

- How often might a particular hazard arise?
- How much harm is likely to result?

Risk is reduced in two ways: by making an undesirable event less likely or by making its outcome less serious. The NRC and the nuclear industry use PRA as one way to evaluate overall risk.

Risk Assessment Methods

To perform a PRA, analysts go through many steps:

1. First, they specify the **hazard** – the outcome(s) to be prevented or reduced. (For nuclear power plants, "core damage" is often used. The core is where the nuclear fuel is arranged, and it is the first physical barrier between radioactivity and the public.)

2. Analysts then identify **initiating events** – those that could possibly lead to the specified consequence (e.g., breakage of a pipe carrying reactor coolant).

3. Analysts then estimate the **frequency** of each initiating event (answering questions such as, "How often do we expect a pipe of this size to break?").

4. Assuming that the initiating event has occurred, analysts identify each combination of failures (e.g., pump failure and valve failure) that lead to a specific outcome.

The likelihood of each combination is then computed. The probabilities of all those sequences that lead to the same outcome are added. To determine how often this outcome might occur, these probabilities are multiplied by the frequency of the initiating event(s).

Modern 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. Analysts use fault trees to identify the combinations of failures that cause the overall system to fail. Then, the fault tree logic is used to calculate the overall failure probability. Analysts pay particular attention to problems that can fail more than one component at the same time.

- *Human reliability analysis* (HRA) is used to evaluate human errors that are important to the outcome of an event. Analysts assess the probability of a mistake in light of factors like training, procedures, and expected conditions during an event.

- *Monte Carlo* methods are used to compute the risks. This technique allows analysts to consider variations in each factor of the analysis, imperfect knowledge, as well as the many possible ways the factors can interact.

Types of Risk Assessments

Even a basic PRA model takes a lot of effort. Fortunately, the speed and power of modern computers allows analysts to use, re-use, and refine each PRA model to address many questions.
The most common nuclear power plant PRAs deal with "internal events" – those that start inside the power plant or the electric system it serves. "External event" PRAs deal with initiating events like earthquakes and hurricanes. Special PRAs are used to address unique problems such as spent nuclear fuel storage cask design or the geology of a potential repository site for high-level radioactive waste.

In the nuclear power industry, analysts label PRAs by "level."

- A Level 1 PRA estimates the frequency of core damage. It starts with conditions that are well known, usually with a reactor operating at full power. All of the systems that work to protect the reactor are modeled. Since the workings of these systems are well understood, the uncertainty of the result is relatively small.

- A Level 2 PRA estimates the magnitude and timing of releases. (That is, "Assuming that the core is damaged, how much radioactivity might escape into the environment?") Uncertainty associated with how much coolant escapes the reactor systems (and how violently), as well as variation in containment system response, makes a Level 2 PRA less precise than a Level 1 PRA.

- A Level 3 PRA assesses the injuries and economic losses that might result if radioactivity escaped from containment. Highly variable factors like wind speed and direction will affect the results.

Risk Assessment Results

PRA results are complex. They do not take the form of a single number. Instead, PRA provides a spectrum of possible outcomes. The frequency with which each of these outcomes is expected is a *distribution* of

values. While it is convenient to summarize the results of a PRA using a single representative value (called a *point estimate*), it is also important to understand how much larger or smaller the actual risks might be.

This uncertainty in the result is partly because reality is more complex than any computer model, partly because modelers do not know everything, and partly because of chance. A certain level of confidence that adequate safety is achieved can be met in either of two ways:

1. Imposing a large enough safety margin to "bound" the risk; or

2. Reducing the uncertainty so that a smaller margin can provide the same (or better) confidence of safety.

Analysts can reduce uncertainty by a) refining their models to more accurately reflect the real world; b) doing research to better understand the physics of what they model; or c) collecting additional data to improve the precision of their models. The NRC does all of these.

NRC Uses of PRA

The NRC developed the first nuclear power plant PRA applications in the 1970s. In the decades that followed, analysts refined their methods and developed new insights on risk. Today, the NRC uses these insights to complement traditional engineering methods when making regulatory decisions about power plants, medical uses of nuclear materials, and the handling of nuclear waste. This is a "risk-informed" approach to regulation, which has included:

- NRC initiatives to have plants perform integrated plant evaluations (using PRA) to discover and correct subtle vulnerabilities, resulting in significant improvements to reactor safety.

- Using PRA insights, inspection programs have shifted their focus to the plant systems, operations and human performance that are most important to safety.

- The reactor oversight program includes a significance determination process (SDP) based on PRA models of each plant. When a piece of equipment fails or is taken out of service for maintenance, its safety significance is assessed. The NRC increases its resources for overseeing nuclear plants as they encounter problems of increasing risk importance.

- In writing or modifying regulations, the NRC often uses PRA to confirm that the new rules are rigorous enough to cover uncertainties – and that new rules include only justifiable requirements.

- PRA is one of several methods used for risk-informed, performance-based regulation of nuclear materials.

- PRA has been used for special analyses, for example, to assess the safety of spent fuel storage casks.

The nuclear industry uses PRA, too:

- Existing plant designs are improved by reducing vulnerabilities discovered through PRA.

- When multiple systems are undergoing maintenance, PRA ensures risk remains low.

- Risk-informed technical specifications and risk-informed in-service inspection programs are used to focus resources on systems and components most significant to safety.

- New reactor designs can be improved prior to submitting applications for certification by the NRC.

PRA use is expected to continue growing as part of a longstanding NRC policy for increased use in all regulatory matters. This should result in a more predictable and timely regulatory approach throughout the agency.

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