# Risk-informed, performance-based safety: Past, present, and future

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*Risk-informed and performance-based approaches to nuclear safety have saved money and improved safety for current reactors and have the potential to offer even greater benefits for advanced reactors.*

Since the 1980s, the nuclear power industry in the United States has worked to enhance the regulatory framework for nuclear facilities by making it more risk informed and performance based (RIPB). This has had some success in improving safety and reducing regulatory burden by focusing resources on the most risk-significant areas and allowing greater flexibility in choosing ways to achieve desired safety outcomes. However, there are further opportunities for the use of RIPB approaches in addressing current regulations and applying implementation tools, and in developing new RIPB regulations and advanced tools to further sharpen the focus on risk and performance outcomes.

**NRC policy background**

In the 1990s, the NRC initiated efforts to put in place regulatory policies and practices to support the use of RIPB in the commercial nuclear industry. The following provides highlights of key features of these efforts over the past 30 years.

In 1995, the NRC issued a policy statement titled *Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities*, which paved the way for broader adoption of risk-informed practices by the NRC and the industry. In 1996, the commissioners issued a staff requirement memorandum (COMSECY-96-061)[1] that stated that in order to accomplish its principal mission in an efficient and cost-effective manner, the NRC would focus its regulatory efforts on licensee activities that pose the greatest risk to the public. In support of this, the agency in 1998 issued a white paper (SECY-98-144)[2] on RIPB regulation that defined terms such as "risk informed" and "performance based" and provided expectations for initiatives related to the implementation of RIPB approaches.

The NRC's efforts continued into the 2000s, with the agency staff developing implementation guidelines for performance-based activities in SECY-00-0191[3] and NUREG/BR-0303[4]. In 2008, the commission updated its expectations regarding advanced reactors by issuing *Policy Statement on the Regulation of Advanced Reactors*. In 2012, the NRC issued a key RIPB document, NUREG-2150[5], which provided a strategic vision and options for adopting a more comprehensive, holistic, risk-informed, and performance-based regulatory approach. That vision reflected and built upon prior NRC policies for the use of RIPB practices and expectations for all the arenas of NRC activities in a comprehensive manner. Although not adopted for current reactors, that strategic vision is embraced in the NRC report *NRC Vision and Strategy: Safely Achieving Effective and Efficient Non-Light Water Reactor Mission Readiness*, issued in 2016. Recently, the NRC staff in SECY-18-0060[6] proposed the development of a performance-based, technology-inclusive regulation as an alternative approach for the licensing of non-light-water reactors. In this paper, the staff also proposed to transform the review process to use risk insights to guide the scope, focus, and depth of a review.

**Outcome attributes**

The NRC's 1998 white paper on RIPB activities provided characteristic attributes and expected outcomes of applying RIPB approaches in regulations. The results of a modern process to design, license, and operate a reactor or enable the use of consensus standards in support of licensing would be characterized by such attributes.

*Outcome attributes of risk-informed safety*: A risk-informed approach to safety decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety. A risk-informed approach enhances the deterministic approach by (1) allowing explicit consideration of a broader set of potential challenges to safety, (2) providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment, (3) facilitating the consideration of a broader set of resources to defend against these challenges, (4) explicitly identifying and quantifying sources of uncertainty in the analysis (although such analyses do not necessarily reflect all important sources of uncertainty), and (5) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Here, prioritization is key; while "risk-informed" means, in part, not relying purely on the probabilistic risk assessment (PRA), it also means being able to say that some scenarios or systems are more important than others and understanding how sure we are about the statements we are making.

*Outcome attributes of performance-based safety*: A performance-based safety approach is one that establishes performance and results as the primary basis for safety decision-making and incorporates the following attributes: (1) measurable (or calculable) parameters (i.e., direct measurement of the physical parameter of interest or of related parameters that can be used to calculate the parameter of interest) exist to monitor the system, including facility and licensee performance, (2) objective criteria to assess performance are established based on risk insights, deterministic analyses and/or performance history, (3) licensees have flexibility to determine how to meet the established performance criteria in ways that will encourage and reward improved outcomes, and (4) a framework exists in which the failure to meet a performance criterion, while undesirable, will not in and of itself constitute or result in an immediate safety concern. A performance-based approach offers two categories of benefits: (1) the focus is on actual performance rather than the satisfaction of prescriptive process requirements, and (2) the burden of demonstrating actual performance can be substantially less than the burden of demonstrating compliance with prescriptive process requirements.

*Outcome attributes of risk-informed and performance-based safety*: A risk-informed and performance-based approach to safety decision-making combines the risk-informed and performance-based elements. Stated succinctly, risk-informed and performance-based safety is an approach in which risk insights, engineering analysis and judgment—including the principle of defense-in-depth and the incorporation of safety margins—and performance history are used to (1) focus attention on the most important activities, (2) establish objective criteria for evaluating performance, (3) develop measurable or calculable parameters for monitoring system and licensee performance, (4) provide flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes, and (5) focus on results as the primary basis for decision-making. By "results" we mean actual safety performance, not demonstrations of adherence to mandated processes or prescriptions.

**RIPB implementation**

The nuclear industry and the NRC have been active in their efforts toward greater use of RIPB practices.

*NRC uses of RIPB practices*: The NRC has taken several actions to implement policies for utilizing RIPB approaches. These include developing risk-informed and, in some cases, performance-based rules and guidance on the following:

■ Maintenance.

■ Modifications to plant-specific licensing basis utilizing Regulatory Guide 1.174[7], including changes to in-service inspections and in-service testing, categorization and treatment of systems, structures, and components (SSC); and changes to technical specifications.

■ Fire protection.

■ Reactor oversight process.

A paper titled "The Evolution of the U.S. Nuclear Regulatory Process"[8] provides an overview from which two specific examples are discussed below.

**Maintenance Rule:** In 1991, the NRC issued 10 CFR 50.65, the Maintenance Rule, which specified a process for monitoring the effectiveness of maintenance, including performance and condition monitoring, and balancing maintenance unavailability and equipment reliability. It also required licensees to assess and manage plant configuration risk that results from taking equipment out of service for maintenance. Before the issuance of the Maintenance Rule, plant operations were governed primarily by prescriptive requirements, such as technical specifications. These requirements dictated what equipment must normally be in service, how long equipment can be out of service, compensatory actions, and surveillance testing to demonstrate equipment readiness. However, while these requirements were aimed at promoting good performance, the performance itself was neither explicitly required nor explicitly confirmed.

**Reactor Oversight Process:** The NRC's Reactor Oversight Process (ROP), developed in the 2000s, focuses safety oversight on performance by structuring goals and objectives that are logically deconstructed from the highest goal of adequate radiological protection[9]. The ROP is an example of how a regulatory initiative significantly influenced the outcomes of reactor operations without changing the rules themselves. Data are now available from almost two decades of ROP practice to show that the performance-based outcome attributes of the RIPB approach can be realized using risk information and performance observations. The program has evolved to encourage improvement in safety focus. The impact is clearly evident from the operational record of current plants in that licensee performance metrics show improvements.

*Industry uses of RIPB practices*: The nuclear industry has supported and taken advantage of the NRC's RIPB guidance and has issued numerous guidance documents to support the implementation of RIPB practices, including the following:

■ The Electric Power Research Institute's (EPRI) topical report on risk-informed in-service inspection programs[10].
■ The Nuclear Energy Institute's guidance on 10 CFR 50.69 SSC categorization[11].
■ NEI's report on the Risk-Informed Technical Specifications Initiative[12].
■ National Fire Protection Association standard, NFPA 805, on performance-based fire protection[13].
■ NEI's guidance for implementing a risk-informed and performance-based fire protection program[14].

Most of the initiatives have been focused on risk-informed applications, with the inclusion of performance-based approaches in many cases. In 2008, EPRI issued a white paper titled *Safety and Operational Benefits of Risk-Informed Initiatives*. The safety benefits include tangible items, such as measured risk reduction, and intangible items, such as improved safety focus. The operational benefits include higher quality, greater plant flexibility, and reduced complexity.

**RIPB challenges**

NRC regulatory policy has moved significantly in the direction of achieving optimization between safety and economics using RIPB approaches. The industry and standards-developing organizations have increasingly committed to develop supporting products so that this can be achieved. Realization of the promise of superior results for advanced reactors requires greater commitment now to integrate RIPB processes in the design, licensing, and operation of such reactors to reap all the possible benefits. However, there is a continuing hesitancy in the industry and the NRC to commit to using RIPB to the fullest effect possible. The primary challenges are NRC related and cost related.

*NRC related*: The technical information required in a licensing application can be simplified if focused on the high-level question (which is the subject of a regulatory review), "Has the applicant presented necessary and sufficient evidence within a license application to justify a conclusion of reasonable assurance of adequate protection of public health and safety, security, and the environment?" Reaching a finding more efficiently on this question is now possible for advanced reactors by taking the perspective of integrated safety outcomes for conducting regulatory reviews.

*Cost related:* Another challenge is the cost of implementing parts of the RIPB approach. The cost of probabilistic risk assessment has grown over time. As PRA standards are updated, attention should be paid to the cost of increasing detail without commensurate risk insights. For advanced reactors, the PRAs can be simpler if the designs are simpler (e.g., NuScale or PRISM), facilitating the realization of the expectations of the NRC's policy statement on advanced reactors.

A significant expense for existing plants has been the recasting and improving of old knowledge bases. For future plants, a considerable investment is required for developing a sufficient understanding of a reactor design to propose appropriate principal design criteria and address construction and operation programs. This is work that is necessary and unavoidable. There is considerable evidence, however, that early investments in pursuing a RIPB approach from scratch will pay greater dividends in reducing regulatory uncertainties and avoiding unnecessary requirements than applying RIPB insights later in the design and deployment processes.

**Why does this matter now?**

At this time, non-LWR licensing is being defined by the NRC and the Department of Energy, and it is at the point that the use of RIPB approaches and results from the industry-led Licensing Modernization Project (LMP)[15] can be incorporated into the various activities.

The current regulatory framework has proven to be effective in protecting public health and safety for the existing LWR fleet, but it is cumbersome and does not take full advantage of technological developments and experience gained from decades of reactor safety analysis and operations. Advanced reactors offer the promise of improved safety and economics, as well as more flexible industrial applications, with simplified operations, maintenance, and surveillance as a result of inherent system characteristics, greater incorporation of passive systems for normal and abnormal conditions, and greater overall safety solution simplicity. A risk-informed and performance-based framework for design and operation can enable advanced reactors to realize reduced licensing timelines and lower capital and operating costs through simpler designs that have fewer unnecessary requirements associated with fabrication, installation, maintenance, and testing of safety-related systems and components.

Furthermore, it is time for the industry, as well as standards-developing organizations such as ANS, to take advantage of the successes of RIPB applications to date to develop standards that will help all stakeholders pursue greater degrees of efficiency and effectiveness. The immediate need is to support and supplement the experts who serve on the ANS Standards Committee to look for early successes that can be replicated for particular applications and then applied to more generic principles, practices, policies, and processes. This frees up regulatory resources, allows for shorter reviews, and provides greater flexibility and support to the designer for meeting shortened schedules. Much more upside potential exists than has been realized so far, and reasons for hesitancy are dissolving. The missing piece is a concerted commitment to formally adopt RIPB processes and make the connections to particular attributes that create benefits that could be more generally achieved.

**Future reactor opportunities**

Going forward, advanced reactors with enhanced safety features involving inherent, passive capabilities, in addition to active safety capabilities essential for normal plant performance, have a significant opportunity to fully utilize the benefits of an RIPB approach to design, licensing, and operations.

The NRC's advanced reactor initiatives are also increasingly recognizing and embracing RIPB approaches for addressing regulatory issues. The commission approved the use of RIPB practices for functional containment determinations in SECY-18-0096[16]. The NRC staff has also developed a draft regulatory guide, DG-1353, *Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Approach to Inform the Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors*, which contains a potential endorsement of the LMP's NEI 18-04, *Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development*, as one means of implementing a RIPB licensing application process with the NRC.

The Advisory Committee on Reactor Safeguards recently recommended that the draft guide and LMP guidance be allowed to move forward. However, this requires that the RIPB process be incorporated early in the development cycle to help shape the results up front. This includes the development of appropriate consensus standards that incorporate advances being made in the licensing area. The LMP has put forward an alternative methodology that completely embraces the NRC's standing policies and expectations, as well as the industry's need for safe, simpler, and more economic nuclear plant options in the future.

The LMP methodology, as summarized in NEI 18-04, provides a technology-inclusive means for an advanced reactor developer and the NRC to reframe the foundations of the safety case in terms of quantitative frequencies and consequences of events modeled in the PRA and measured against toplevel NRC performance-based parameters. An important aspect of this methodology is the integrated nature of the evaluation of plant-level safety outcomes. The basic process involves a thorough understanding of plant capability to achieve the predicted event outcomes; the use of programmatic activities to ensure that the plant is built, operated, and maintained in a manner that provides confidence in the performance of safety-significant SSCs and human actions; and systematic consideration of the defense-in-depth philosophy throughout the development and licensing process. The overall RIPB framework for this methodology is shown in Fig. 1. The NEI guidance is presently undergoing NRC review.

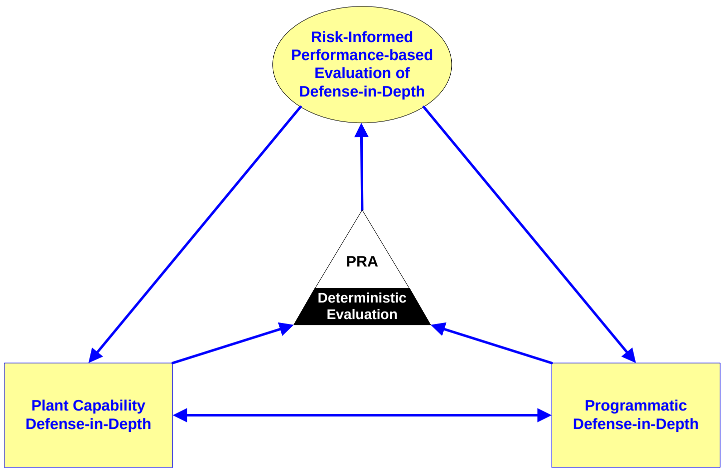


**Figure 1: The Licensing Modernization Project framework**

In addition, an opportunity exists for future reactors to meet safety objectives without the imposition of unnecessary requirements on new designs. In DG-1353, the NRC staff points out that the design process and related development of licensing-basis information is an iterative process involving RIPB assessments and decisions on key SSCs, operating parameters, and programmatic controls to ensure that the reactor can be deployed without posing undue risk to public health and safety. This information is important to specify acceptance criteria for the analyses of licensing-basis events and as an input into the analysis of dose consequences from potential accidents. The relative novelty of advanced reactors shifts the burden of defining the proper regulatory review framework back to the applicant as the NRC moves more toward safety-focused, performance-based reviews consistent with SECY-18-0060 objectives. Also, systematic use could be made of qualitative and quantitative risk and safety insights to scale the information to be submitted to focus more on the determination of safety adequacy. This is more obtainable today with early, effective NRC pre-application engagement as encouraged in the NRC's advanced reactor policy.

The submittal by the LMP of NEI 18-04 for endorsement enables the staff to appropriately balance the regulatory principles of reliability, clarity, and efficiency to accept elements of uncertainty in areas of low safety significance, consistent with the approach proposed in SECY-18-0060.

There are other signals that it is time now to move forward with greater use of RIPB practices. In January 2019, the Nuclear Energy Innovation and Modernization Act (NEIMA) was signed into law with bipartisan support. It includes requirements for the NRC to "develop and implement, where appropriate, strategies for the increased use of risk-informed and performance-based licensing evaluation techniques and guidance for commercial advanced nuclear reactors within the existing regulatory framework, including evaluation techniques and guidance."

The nuclear industry and standards-developing organizations can play a large role in support of implementing NEIMA strategies for increased use of RIPB approaches.

**ANS initiatives**

In 2017, ANS issued Position Statement 46[17] on the value and importance of further use of RIPB practices. The ANS Standards Board has assessed the issue of achieving modernization of its standards and has included specific goals for achieving results in this area. The ANS Standards Committee Strategic Plan calls for greater emphasis and priority on developing new RIPB standards, amending existing standards where appropriate, and filling in gaps in standards where industry needs are clear. As part of that process, when a standard comes up for maintenance or a new standard is proposed, it is reviewed for greater use of RIPB practices.

ANS has also worked in close partnership with ASME to support the development and implementation of PRA standards. As part of this effort, the ASME/ANS Joint Committee on Nuclear Risk Management was formed in 2010 and has issued several PRA standards and established subcommittees (including the Subcommittee on Risk Applications) to support the industry in applying risk tools[18]. With the LMP, the nuclear industry has taken the lead in proposing an integrated RIPB design and safety-assessment methodology for use by the advanced reactor community to design and license non-LWR plant types.

Further, ANS has supported the NRC during its annual NRC Standards Forum, which brings together standards-developing organizations to discuss the overlapping needs for updated standards as part of nuclear industry revitalization. With the enactment of NEIMA, legislative support is available for increased investment in the development of RIPB methods, as well as standards the industry needs to support its licensing efforts. The Risk-informed, Performance-based Principles and Policy Committee, established by the ANS Standards Board, has been working on supporting the Standards Committee with RIPB methods. ANSI/ANS-53.1–2011 (R2016), *Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants* was issued eight years ago and is being used in advanced reactor work. A proposed new standard, ANS-30.1, *Integrating Risk and Performance Objectives into New Reactor Nuclear Safety Designs*, is being developed. These are just two of a number of initiatives being carried out under the direction of the ANS Standards Board.

**Going forward**

Although much progress has been made in developing an RIPB regulatory policy framework and implementing it in selective areas to improve nuclear safety, much work remains to take full advantage of the benefits of the RIPB approach. It has proven useful to relax some current requirements, but it has been difficult to eliminate requirements that do not contribute to safety but that remain embedded in the licensing basis of existing reactors. For future plants, the opportunity exists to design the desired framework from scratch to more effectively accommodate uncertainties associated with any new venture and to reduce the unnecessary burdens imposed because of insignificant safety concerns or compliance-centric requirements that do not contribute to achieving safety objectives. It will take some time, but the time is right to fully embrace the opportunity to use RIPB techniques, starting from the foundation defined in the LMP to build a better, more safety-focused, and efficient nuclear industry.

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