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PROBABILISTIC RISK ASSESSMENT REQUIREMENTS FOR NEW LIGHT WATER REACTORS

Mr. Hanh K. Phan, Mr. Martin A. Stutzke,
Mr. Donald G. Harrison, and Ms. Lynn A. Mrowca
U.S. NRC
11555 Rockville Pike
Rockville, MD 20555
Hanh.Phan@nrc.gov; Martin.Stutzke@nrc.gov;
Donald.Harrison@nrc.gov; Lynn.Mrowca@nrc.gov

ABSTRACT

Probabilistic risk assessments (PRAs) have been used by the U.S. Nuclear Regulatory Commission (NRC) as a valuable complement to the NRC's deterministic approach for a number of years. Their use in regulatory decision making and licensing activities has increased in recent years following the issuance of the Commission's PRA policy statement in 1995 and additional Commission guidance issued in 1997. Subsequently, additional PRA and risk-informed changes have been incorporated in the requirements of Title 10 of the Code of Federal Regulations (10 CFR), especially Part 52 "Licenses, Certifications, and Approvals for Nuclear Power Plants" and the associated requirements in Part 50 applicable to new reactors. These regulations include requirements to develop and maintain PRAs. Regulatory guidance was also developed to address these requirements for design certification (DC) and combined license (COL) applications with respect to the use of PRA in regulatory activities.

This paper discusses the new regulatory requirements and issued guidance pertaining to the DC applicants, COL applicants, and holders of a COL from a PRA perspective and future considerations associated with implementing these new changes.

Key words: New Reactor Applications, Design-Specific PRA, Plant-Specific PRA, Regulations, Regulatory Guidance

1 INTRODUCTION

For the past many years, a number of PRAs have been developed to varying degrees to support risk-informed regulations and applications. The NRC has been moving from the traditional regulatory approach toward more of a risk-informed, performance-based approach which relies on the insights derived from PRA results for decision-making. The goal is to make a sound safety decision based on technically defensible information.

For new light water reactors, the Commission originally issued 10 CFR Part 52 on April 18, 1989, which provided the licensing requirements and review procedures for new design certification and combined license applications. The Commission's intention was to achieve the early resolution of licensing issues, as well as to improve the effectiveness and efficiency of the licensing process. Per this regulation, an application for a DC was required to contain a design-specific PRA. In August 2007, the Commission issued a revision to 10 CFR Part 52. This revision to the regulation now requires that a DC application only contain a description of the design-specific PRA and its results. In addition, a new requirement was added such that COL applications must contain a final safety analysis report (FSAR) that includes a description of the plant-specific PRA and its results. Furthermore, 10 CFR Part 50 was also revised to include PRA maintenance requirements for each holder of a COL.

To address these new rules, regulatory guidance (Refs. 1, 2, 3, and 4) has been developed with respect to the PRA and its uses in DC and licensing activities. Specifically, new reactor applications should include a description of the PRA and its quantitative results in Chapter 19 of their design-specific or plant-specific FSAR, including a summary of risk metrics, descriptions of significant core-damage and large-release sequences, identification of significant initiating events and their percent contributions to the risk metrics, and identification of significant functions, operator actions, and systems, structures, and components with their risk achievement worth and Fussell-Vesely importance measures. In the DC and COL application phases, the use of PRA includes but is not limited to the following areas:

- Identify and address potential design features and plant operational vulnerabilities.

- Reduce or eliminate the significant risk contributors.

- Identify risk-informed safety insights based on systematic evaluations.

- Demonstrate how the risk associated with the design compares against the Commission’s quantitative goal of less than 1E-4/yr for core damage frequency (CDF) and less than 1E-6/yr for large release frequency (LRF).

- Determine how the risk associated with the design compares against the Commission’s containment performance goal, that the containment integrity be maintained for approximately 24 hours following the onset of core damage and the conditional containment failure probability (CCFP) be less than 0.1 for the composite of all core-damage sequences assessed in the PRA.

- Obtain risk insights associated with establishing allowed outage times for certain equipment technical specifications and procedure development.

- Provide PRA importance measures and insights for input to other programs, i.e., the regulatory treatment of nonsafety systems, regulatory oversight processes, maintenance rule, reliability assurance program, inspections, tests, analyses and acceptance criteria, and security.

In addition, the PRA results and insights are being used by the NRC staff to enhance the DC and COL application technical reviews by helping the reviewers to focus their attention and resources upon aspects of the design that contribute most to plant safety.

2 REGULATIONS PERTAINING TO NEW REACTOR APPLICANTS

The Commission approved the final rule amending 10 CFR Part 52 for new reactors in April 2007 with changes and comments. The final rule was issued in August 2007. A summary of the PRA-related changes in the final 10 CFR Part 52 rule and other associated regulations is provided below:

1. For DC applicants, 10 CFR 52.47(a)(27) states that a DC application must contain an FSAR that includes a description of the design-specific PRA and its results. The Statement of Consideration [72 FR 49380] for the revised Part 52 states that the complete PRA (e.g., codes) will be available for NRC inspection at the applicant's offices, if needed. The NRC expects that, generally, the information that it needs to perform its review of the DC application from a PRA perspective is that information that will be contained in applicants' FSAR Chapter 19.

2. For COL applicants, 10 CFR 52.79(a)(46) states that a COL application must contain an FSAR that includes a description of the plant-specific PRA and its results. The Statement of Consideration [72 FR 49387] for the revised Part 52 states that the complete PRA (e.g., codes) would be available for NRC inspection at the applicant's offices, if needed. The NRC expects that, generally, the information that it needs to perform its review of an application from a PRA perspective is that information contained in applicants' FSAR Chapter 19.

   10 CFR 52.79(d)(1) states that if a COL application references a DC, then the plant-specific PRA information must use the PRA information for the DC and must be updated to account for site-specific design information and any design changes or departures. The Statement of Consideration [72 FR 49388] states in the case where a COL application is referencing a DC, the NRC only expects the design changes and differences in the modeling (or its uses) pertinent to the PRA information to be addressed to meet the submittal requirement of 10 CFR 52.79(d)(1).

3. For COL holders, 10 CFR 50.71(h)(1) states that no later than the scheduled date for initial loading of fuel, each holder of a combined license shall develop a level 1 and a level 2 PRA. The PRA must cover those initiating events and modes for which NRC-endorsed consensus standards on PRA exist one year prior to the scheduled date for initial loading of fuel. The Statement of Consideration [72 FR 49362 and 72 FR 49405] states that it is not required to submit this PRA to the NRC, but instead should be maintained by the licensee for NRC inspection. The need for any such submittal or review would be determined by any risk-informed application for which the licensee might wish to use this PRA, such as in support of licensing actions. It is further stated [72 FR 49405] that the 1-year time period was chosen to allow time for the licensee to develop and upgrade its PRA and conduct peer review prior to the date when the PRA must be completed (i.e., by the scheduled date for initial fuel load). The scheduled fuel load date was selected because the COL holder chooses this date, and thus is in a position to determine when the "one-year prior" requirement comes into effect.

10 CFR 50.71(h)(2) states that each COL holder must maintain and upgrade the PRA required by 10 CFR 50.71(h)(1). The upgraded PRA must cover initiating events and modes of operation contained in NRC-endorsed consensus standards on PRA in effect 1 year prior to each required upgrade. The PRA must be upgraded every 4 years until the permanent cessation of operations under 10 CFR 52.110(a). With respect to this regulation, the Statement of Consideration [72 FR 49405] states that the Commission intends PRA maintenance and PRA upgrade to be consistent with how they are defined in the American Society of Mechanical Engineers (ASME) "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications" (ASME-RA-Sb-2005). Additionally, the Statement of Consideration [72 FR 49405] states that if no new standards are issued during a four-year upgrade cycle, licensees would not be required to upgrade their PRAs; however, the requirement to maintain the PRA would still be in effect. It should also be noted that there may be situations where a PRA upgrade is needed more frequently than the four-year cycle, as for instance to support a new risk-informed application.

10 CFR 50.71(h)(3) states that each COL holder must, no later than the date on which the licensee submits an application for a renewed license, upgrade the PRA required by 10 CFR 50.71(h)(1) to cover all modes and all initiating events. With respect to this regulation, the Statement of Consideration [72 FR 49405-49406] states that this requirement is not premised on the existence of NRC-approved consensus standards, and an all-mode, all-initiator PRA must be developed even if standards do not yet exist. Also, the Statement of Consideration [72 FR 49406] states that the requirement to develop and maintain such a PRA by the time of license renewal application is intended only to establish a timing requirement for completing the upgrade of the PRA, and does not have any implications on the current requirements for license renewal. The upgraded PRA is not an element of any (i.e., past, present, or future) review or approval of a license renewal application.

Since the revised 10 CFR Part 52 now requires DC and COL applicants to submit a description of the PRA and summary of its results instead of the PRA documentation, the NRC staff may formally request additional information or perform on-site audits if the staff needs more information during the safety review of the applications. Also, some DC applicants have provided access to their PRA documentation by submitting it for information or by having the documentation available locally for on-site audits, as necessary. This easy access allows the staff to more quickly understand the PRA information and its basis in the design control document without engaging the applicant as frequently, allowing for a more efficient review.

3 REGULATORY GUIDANCE PERTAINING TO PRA FOR NEW REACTOR ACTIVITIES

The NRC staff has developed and revised regulatory guidance for new reactor applications with respect to the PRA and its uses in regulatory activities. Commission approval for the amended 10 CFR Part 52 was issued in April 2007 allowing a very short time for regulatory guidance finalization and application changes, since the first COL applications were expected in September 2007 and new DC applications were expected in December 2007. The primary guidance documents, NUREG-0800 and RG 1.206, were completed in June 2007. These and other guidance documents are summarized below:

1. U.S. NRC Standard Review Plan (SRP), NUREG-0800, Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors Review Responsibilities"

   In June 2007, NUREG-0800, Chapter 19 (Ref. 1) was reorganized and guidance for new reactor reviews was added as Section 19.0. This SRP section was developed to provide guidance to the staff pertaining to the review of the design-specific PRA information for DC and plant-specific PRA information for a COL application. As discussed in this new section, the FSAR for either a DC or COL application needs to provide a description of the PRA and its results. This requirement is intended to be a qualitative description of insights and uses, as well as some quantitative PRA results, such that the staff can perform the review, ensure risk insights were factored into the design, and make the evaluation findings. NUREG-0800 also indicates that, the complete PRA (e.g., models, analyses, data, and codes) should be available for NRC audit.

2. U.S. NRC Regulatory Guide 1.206 – "Combined License Applications for Nuclear Power Plants"

   In June 2007, the NRC issued Regulatory Guide (RG) 1.206 (Refs. 2 and 3) to provide prospective COL applicants with guidance concerning the format and content of a COL application. Generally, information in this RG is reflected in NUREG-0800. Section C.I.19 "Probabilistic Risk Assessment and Severe Accident Evaluation" and Section C.III.1 "Information Needed for a Combined License Application Referencing a Certified Design" of this document identify the PRA-related information that should be submitted with a COL application. According to this RG, a COL applicant should provide in Chapter 19 of the FSAR an adequate level of documentation to enable the NRC staff to determine the acceptability of the risks to public health and safety associated with operation of the proposed new plant. The acceptability of the risks to public health and safety is determined from the interpretation of the results and insights of the applicant's plant-specific PRA. Use of this guidance should facilitate both the preparation of a COL application by the applicant and the timely review of the application by the NRC staff.

3. Interim Staff Guidance COL/DC-ISG-003 "PRA Information to Support Design Certification and Combined License Applications"

   After the issuance of the SRP revision and RG 1.206 in June 2007, the NRC staff held a public meeting in July 2007 to discuss the change in regulations relating to PRA and the

PRA portions of the recently issued regulatory guidance. Through discussions at this meeting and other public meetings with various industry organizations and DC and COL applicants, the staff recognized that supplementing the guidance provided in SRP Section 19.0 and RG 1.206 was needed to clarify its expectations with respect to PRA information used to support DC and COL applications. Based on these discussions, the staff issued proposed interim staff guidance (ISG) in the Federal Register on February 12, 2008, to solicit public and industry comment. Comments were received, dispositioned, and the final ISG COL/DC-ISG-003 (Ref. 4) was issued on June 11, 2008. The key guidance includes:

- PRA Summary Results: For the PRA summary of results, the new reactor applicants should provide quantitative and qualitative (e.g., PRA assumptions, PRA-based insights) information. Regulatory guidance notes that significant results should be provided, using the same definition for "significant" that is in RG 1.200 (Ref. 5) and that the definitions of "significant accident sequence" and "significant contributor" are suitable for both large early release frequency and LRF. In addition, the internal events PRA quantitative results should include internal floods and their contributions. For a COL application that references a certified design with design changes or departures from the certified design, the staff expects COL applicants to submit the PRA numerical changes when the cumulative risk impact of the changes resulting from the COL departure is more than a 10% change (either positive or negative) in the total core-damage frequency or total LRF from the DC PRA. In addition, all changes or departures from the design that result in a revision of PRA-based qualitative results should be reported to the NRC, including key assumptions and risk insights.

- PRA Quality: To make effective use of PRA and its insights for DC and COL applications, the staff needs to have confidence in the quality of the PRA to support the application. As discussed in RGs 1.174 (Ref. 6) and 1.200, the quality of a PRA is measured in terms of its appropriateness with respect to scope, level of detail, and technical adequacy.

  The expected scope and level of detail used to support a DC or COL application is specified in SRP Section 19.0 and RG 1.206. In addition to this guidance, the NRC may allow (on a case-by-case basis) the use of design acceptance criteria (DAC) in specific areas (i.e., radiation protection, piping, instrumentation and controls (I&C), and human factors engineering) for DC applicants in lieu of detailed design information. However, DC applicants should still address those portions of the design covered by DAC in the design PRAs to the extent practicable or the applicant should identify those areas that they deem as not practicable to model and qualitatively assess their impacts on the PRA results and insights. Any assumptions made regarding the reliability or performance of structures, systems, and components under DAC during this process will be verified when the design is finalized.

  RG 1.200 contains the staff's guidance concerning PRA technical adequacy, including the use of peer reviews. The January 2007 issuance of RG 1.200 endorses a peer review of risk-informed applications, without specifically noting applicability to new reactor applications. Until RG 1.200 is revised to address new reactors, COL/DC-ISG-003 notes that peer reviews are not required for DC applications. However, DC applicants and COL applicants/holders must still adequately address the quality of their PRA. If necessary, the NRC staff may also conduct an audit of the PRA for technical adequacy. COL/DC-ISG-003 provides further guidance for adequate level of detail and supporting and high level requirements associated with the Capability Category in the ASME RA-S-2002 PRA standard and addenda (Ref. 7).

- PRA Maintenance and Upgrade: PRA maintenance should commence at the time of application for both DC and COL applicants. Therefore, the PRA should be updated to reflect plant modifications if there are changes to the design. COL applicants should describe their PRA maintenance process in FSAR Chapter 19. Once the certification is issued, DC applicant's PRA would not need to be updated except as appropriate in connection with a DC amendment request.

  The ASME PRA Standard describes "PRA upgrade" as the incorporation into a PRA model of a new methodology or significant changes in scope or capability. This could include items such as new human error analysis methodology, new data update methods, new approaches to quantification or truncation, or new treatment of common cause failure. PRA upgrade should commence no later than the scheduled date for initial fuel load. Therefore, COL holders must upgrade the PRA used to support the COL to cover those initiating events and modes of operation contained in NRC-endorsed consensus standards that exist one year prior to each required upgrade.

4. Interim Staff Guidance DI&C-ISG-003 "Digital Instrumentation and Controls"

The NRC staff is in the final phase of issuing the digital instrumentation and control (I&C) ISG (Ref. 8) which will provide additional guidance on how NRC staff should evaluate a digital I&C system in the PRA. This ISG mainly addresses an acceptable method for evaluation of I&C systems including common cause failures and uncertainty analysis associated with the digital systems. In the past, comprehensive deterministic guidance was developed by the NRC and industry for operating plants, as well as new power plants, to address the unique failure modes of digital I&C systems (i.e., common cause digital system failures). The deterministic guidance is designed to help assure that adequate defense-in-depth is maintained such that the effects of digital I&C system common cause failures are appropriately limited. Currently, a project is underway by the NRC to develop a set of metrics for evaluating the quality of digital system development processes. Additionally, the NRC has a long-term project to determine if risk assessment methods are available or can be developed to more accurately model digital I&C risk so that insights can be used to make better risk-informed decisions.

The NRC and industry recognize that current PRA methods can provide high-level useful risk information about digital I&C systems, but they have limited application in making risk-informed decisions. To date, the reviews of new reactor PRAs have provided limited but important insights into digital I&C systems, in particular in the area of identifying assumptions and parameters that must be assured to be valid in the as-built, as-operated nuclear power plant. Accordingly, the NRC has developed ISG for NRC staff on how to review digital I&C system risk assessments based on the lessons learned from previously accepted new reactor digital I&C system PRA reviews.

4 LOOKING FORWARD

Implementing the revised 10 CFR Part 52 for new light water reactors has lead to many regulatory changes for both the NRC staff and the DC applicants and COL applicants/holders. The use of technology new to the nuclear power industry has been used in the design of these plants which may lead to re-evaluating current modeling methods (e.g., human reliability analysis and digital I&C). In addition to the new PRA requirements, the application of risk-informed initiatives is being considered by some of the new reactor applicants. As new reactor applications are reviewed, design certifications and licenses issued, and plants are constructed and operated, future changes to industry standards and regulatory guidance may be necessary.

Industry Standards

The revised 10 CFR Part 50.71(h)(1) specifically requires a holder of a COL to develop a level 1 and level 2 PRA no later than the scheduled date for initial loading of fuel covering the initiating events and modes for which NRC-endorsed consensus standards exist. Currently, there are PRA standards for full-power, internal events (excluding fire) level 1 and limited level 2 (Ref. 7), external events (Ref. 9), and a combined ASME and ANS level 1 and limited level 2 standard for internal and external events for at-power conditions (Ref. 10). ANS is also developing a level 1 and limited level 2 PRA standard for low power / shutdown operating modes (to be incorporated in the ASME and ANS combined standard) and level 2 and level 3 PRA standards.

In the longer term, the revised 10 CFR Part 50.71(h)(3) specifically requires a holder of a COL to upgrade the PRA to cover all modes and all initiating events by the time the licensee submits an application for a renewed license, regardless of whether there are existing standards or NRC endorsement of those standards.

Regulatory Guidance

It is recognized that a number of regulatory guides related to PRA were primarily developed for the current fleet of operating nuclear reactors. Therefore, this guidance may need to be reviewed for applicability to new reactors. These regulatory guides address PRA technical adequacy (RG 1.200); categorization of structures, systems, and components based on their safety significance (Ref. 11); and the use of PRA in licensing decisions for plant specific changes (RG 1.174), inservice testing (RG 1.175, Ref. 12), technical specifications (RG 1.177, Ref. 13), and inservice inspection of piping (RG 1.178, Ref. 14). If these risk-informed applications will be used for new reactors, new reactor considerations should be adequately addressed in the regulatory guidance documents to ensure that there are no potential issues with the application of these RGs. For example, a preview of the proposed revision to RG 1.200 has been publically discussed which includes consideration of the new light water reactors. These considerations include adding reference to LRF (in addition to large early release frequency) for new reactors, adjustment of screening values for external hazards and initiating events analysis, acceptable use of seismic margin analysis, and industry peer review.

Risk-Informed Applications

A number of currently operating power plants are pursuing plant-specific license amendments to revise their technical specifications based on risk-insights (i.e., risk-informed technical specification initiatives). Although several documents and standards have been developed to address these risk-informed applications, the guidance for applying these options to new reactors may still need to consider the limited level of design and operational details for new reactors in the application stage (which could lead to conservatisms and assumptions in the PRA), the lack of data to derive a plant-specific PRA database, increased emphasis on the use of mitigating passive systems for some designs, and the lack of industry operating insights and service experience on newly designed systems, structures, and components.

These issues need to be further examined to ensure acceptable implementation of the Commission's guidance on risk-informed applications and adequate protection of the public health and safety.

5 CONCLUSION

There have been recent changes in the regulations pertaining to the DC applications, COL applications, and COL holders from a PRA perspective, which required the development of and revision to regulatory guidance available to the new reactor applicants and NRC staff. As the NRC and the nuclear power industry move toward obtaining the full benefit offered by PRA in risk-informed regulation, a clear understanding and delineation of standards, regulatory requirements, limitations, and applicability of approaches for new light water reactors should be pursued.

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