ASME/ANS RA-S-1.4-2021

Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

ANS

Date of Issuance: February 8, 2021

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The American Society of Mechanical Engineers
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FOREWORD

The American Society of Mechanical Engineers (ASME) Board on Nuclear Codes and Standards (BNCS) and the American Nuclear Society (ANS) Standards Board mutually agreed in 2004 to form the Nuclear Risk Management Coordinating Committee (NRMCC). NRMCC was chartered to coordinate and harmonize standards activities related to probabilistic risk assessment (PRA) between ASME and ANS. A key activity resulting from NRMCC was the development of PRA standards structured around the Levels of PRA (i.e., Level 1, Level 2, Level 3) to be jointly issued by ASME and ANS. In 2011, ASME and ANS decided to combine their respective PRA standards committees to form the ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM).

In 2006, ASME BNCS established the New Reactor Task Group under the Committee on Nuclear Risk Management (CNRM) to evaluate the need for codes and standards to support the design, construction, licensing, and operation of advanced non-light water reactor (non-LWR) nuclear power plants (NPPs). Following the formation of JCNRM, the New Reactor Task Group is now known as the ASME/ANS JCNRM Advanced Non-LWR PRA Standard Writing Group (Non-LWR WG). The charter of the Non-LWR WG is to develop recommendations to JCNRM on requirements for the performance of PRAs for advanced non-LWRs. The expected applications of such PRAs include input to licensing and design decisions such as selection of licensing-basis events and safety classification of equipment, satisfaction of U.S. Nuclear Regulatory Commission (NRC) PRA requirements for advanced non-LWRs, and support of risk-informed applications for advanced non-LWR NPPs. With the concurrence of JCNRM, the Non-LWR WG decided early on that a new PRA standard was needed to support a broad range of applications for advanced reactor designs.

To support a diverse mixture of reactor concepts, including high-temperature gas-cooled reactors, liquid metal-cooled fast reactors, molten salt reactors, microreactors, and small modular reactors, CNRM decided early on to develop this new PRA standard on a reactor-technology-neutral basis using established technology-neutral risk metrics common to existing light water reactor (LWR) Level 3 PRAs. Such risk metrics include frequency of radiological consequences (e.g., dose, health effects, and property damage impacts). To support a wide range of applications defined by the non-LWR stakeholders, the scope of this Standard is very broad and is comparable to a full-scope Level 3 PRA for an LWR with a full range of plant operating states and hazards. Because some of the advanced non-LWR designs supported by this Standard include modular reactor concepts, this Standard includes requirements that support an integrated risk of multi-reactor facilities including event sequences involving two or more reactors or radionuclide sources concurrently.

In 2013, the JCNRM issued a trial use for the pilot application (TUPA) version of this Standard as ASME/ANS-RA-S-1.4-2013. This trial use version was extensively piloted in the development of a number of advanced non-LWR PRAs that were under development and being built around the world. These advanced non-LWR PRA pilots included one to support the licensing of the HTR-PM pebble bed reactor plant in the Republic of China and a modernization of the GE PRISM PRA, which piloted a major fraction of this Standard's technical requirements in 2018. The experience with pilot applications of this Standard has been extended to support the development of the Traveling Wave and Molten Chloride Fast Reactor at TerraPower, the pebble bed HTGR under development at X-Energy, the Versatile Test Reactor being developed for the U.S. Department of Energy, the Fluoride Cooled High Temperature Reactor at Kairos, the eVinci™ Micro Reactor at Westinghouse, and Advanced HTGRs under development in Japan. The purpose of this version of this Standard is to capture the lessons learned from these pilot applications and to incorporate improvements that have been made in other PRA standards that are applicable to advanced non-LWRs.

In preparing the technical requirements in this Standard, the Non-LWR WG made use of applicable source material from PRA standards that have been developed for LWRs including ASME/ANS RA-Sb-2013, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," as well as Trial Use PRA standards developed by ASME and ANS for Low-Power-and-Shutdown PRA, Level 2 PRA, and Level 3 PRA.

This publication, the 2021 edition of Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants, was approved by the ASME Board on Nuclear Codes and Standards and the ANS Standards Board. ASME/ANS RA-S-1.4-2021 was approved by the American National Standards Institute on January 28, 2021.

CORRESPONDENCE WITH THE ASME/ANS JOINT COMMITTEE ON NUCLEAR RISK MANAGEMENT

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Secretary, ASME/ANS Joint Committee on Nuclear Risk Management
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

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Proposed Reply(ies)	Provide a proposed reply(ies) in the form of “Yes” or “No,” with explanation as needed. If entering replies to more than one question, please number the questions and replies
Background Information	Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

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ACKNOWLEDGMENTS

This edition of the advanced non-LWR PRA Standard was the result of the dedicated efforts of the following individuals who are responsible for the changes made to the 2013 trial use version of this Standard: Jordan Hagaman, Peiwen Whysall, Matthew Denman, and Matthew Warner at Kairos Power; Marty Sattison, Individual; Andrew Clark and Jamal Mohmand of Sandia National Laboratory; David Grabaskas of Argonne National Laboratory; Dennis Henneke of GE Hitachi Nuclear Energy; Hanh Phan of the U.S. Nuclear Regulatory Commission; and Karl Fleming, KNF Consulting Services, LLC.

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SECTION 1 – INTRODUCTION
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(The text presented in blue font in this standard comprise hyperlinks to enable efficient access to referenced sections and elements, requirements, notes, references, etc.)

SECTION 1 INTRODUCTION

1.1 OBJECTIVE

This Standard[1] states the requirements for probabilistic risk assessments (PRAs) used to support risk-informed decisions for advanced non-light water reactor (non-LWR) nuclear power plants (NPPs) and prescribes a method for applying these requirements for specific applications. To support the application of this Standard to PRAs for a diverse set of reactor designs such as modular high-temperature gas-cooled reactors (MHTGRs), liquid metal-cooled fast reactors (LMRs), molten salt reactors (MSRs), micro-reactors and small modular reactors based on non-LWR technology, and other advanced non-LWRs, the requirements in this Standard were developed on a reactor-technology-inclusive basis. This Standard supersedes an earlier trial use version ASME/ANS RA-S-1.4-2013 [1-1][2] and incorporates feedback from pilot studies using that version.

1.2 SCOPE

This Standard states requirements for a PRA for advanced non-LWR NPPs. The requirements in this Standard were developed for a broad range of PRA scopes that may include the following:

(a) Different sources of radioactive material both within and outside the reactor but within the boundaries of the plant whose risks are to be determined within the PRA scope selected by the user;

(b) Different plant operating states, including various levels of power operation and shutdown modes;

(c) Initiating events caused by internal hazards, such as internal events, internal fires, and internal floods, and external hazards such as seismic events, high winds, and external flooding. The only hazards explicitly excluded from the scope are releases resulting from purposeful human-induced security threats (e.g., sabotage, terrorism);

(d) Different event sequence end states, including those with no adverse consequences, plant damage states (PDSs), and release categories that are sufficient to characterize mechanistic source terms, including releases from event sequences involving two or more reactors or radionuclide sources;

(e) Evaluation of different risk metrics including the frequencies of modeled PDSs, event sequence families, release categories, risks of off-site radiological exposures and health effects, and the integrated risk of the multi-reactor plant as defined by the selected PRA scope. The risk metrics supported by this Standard are established metrics used in existing light water reactor (LWR) Level 3 PRAs such as frequency of radiological consequences (e.g., dose, health effects) that are independent of reactor technology. Surrogate risk metrics used in LWR PRAs such as core damage frequency (CDF) and large early release frequency (LERF) are not applicable to many non-LWR designs and not used in this Standard;

(f) Quantification of the event sequence frequencies, mechanistic source terms, off-site radiological consequences, risk metrics, and associated uncertainties, and using this information to support risk-informed decisions in a manner consistent with the scope and applications PRA.

Technical requirements are provided in this Standard for different combinations of sources of radioactive material, plant operating states, and hazard groups. In this Standard, the technical requirements for the internal fire hazard group are limited to “at-power” plant operating states as there was insufficient experience in performing internal fire PRAs during low power and shutdown (LPSD) plant operating states to justify the inclusion of such requirements. This exclusion is consistent with supporting LWR PRA standards. Other combinations of hazard groups and plant operating states are, however, supported in this Standard.

It is recognized that for some PRA applications, a PRA that addresses the full set of requirements covered in this Standard may not be required. In addition, for PRAs performed in various stages of design and licensing, especially those PRAs performed prior to the selection of a specific site, the level of detail and completeness of the PRA with respect to the PRA scope, coverage of events and event sequences, plant operating states, hazards, risk metrics, and operational characteristics may be limited in relation to that for typical PRAs for an operating plant. Hence, the scope of the PRA is established by the user in accordance with the intended PRA applications and the availability of information to support each PRA element. In addition, the requirements in this Standard for the level of detail, completeness, and model to plant or design fidelity vary according to the scope and level of detail of design and operational information that is available to support, and is referenced by, the PRA with additional requirements to address assumptions in lieu of as-operated and as-built details.

[1] The current Standard, ASME/ANS RA-S-1.4-2021, is herein referred to as “this Standard.”

[2] Numbers in brackets refer to corresponding reference numbers at the end of each section in “Reference(s).”