



Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants

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**American National Standard
Nuclear Safety Design Criteria
and Functional Performance
Requirements for Liquid-Fuel
Molten Salt Reactor Nuclear
Power Plants**

Secretariat
American Nuclear Society

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**American Nuclear Society
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Foreword

(This foreword does not contain any requirements of American National Standard ANSI/ANS-20.2-2023, *Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants*, but is included for informational purposes.)

This standard provides nuclear safety design criteria for liquid-fueled molten salt reactor (MSR) nuclear power plants (NPPs) including those that produce nonelectrical forms of power. The design criteria enable developing reasonable assurance that liquid-fueled MSR NPPs are designed so that they can be operated without undue risk to the public health and safety or to the environment. This standard also provides an MSR-focused description of a risk-informed design process following the methodology endorsed in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.233 (Rev. 0, 2020), “Guidance for a Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors.” This standard defines safety objectives, MSR design criteria, and definitions of MSR terminology important for safety evaluation. This standard describes distinctive safety considerations for MSRs and is intended to provide necessary guidance to the designer in order to “bridge” the existing light water reactor (LWR)–focused general design criteria (GDCs) contained in *Code of Federal Regulations* (CFR) Title 10, “Energy,” Part 50, “Domestic Licensing of Production and Utilization Facilities,” Appendix A, “General Design Criteria for Nuclear Power Plants,” and other regulatory requirements to the development of their respective principal design criteria (PDCs), while retaining the underlying safety principles of the GDCs.

PDCs for MSRs may be developed using the minimum requirements for nuclear power plant PDCs established in 10 CFR 50 Appendix A using the process described in RG 1.232 (Rev. 0, 2018), “Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors,” or, indirectly, using a risk-informed, performance-based process as described in RG 1.233. As with other standards that have been developed by standards development organizations, it is anticipated that this standard will be reviewed by the national nuclear regulator, which will, in turn, use it as input for issuance of regulatory guidance specific for this class of reactors. This standard applies to all MSR NPPs, independent of power level, commercial application, number of reactor modules on-site, or salt composition. This standard encompasses all heat transport systems and is not restricted to a particular configuration (loop, pool, hybrid, or other arrangements). This standard also pertains to on-site storage of used fuel prior to its removal for recycling or long-term storage.

This standard does not directly address plant security design criteria, except to note the importance of integrating security into the design of the reactor to minimize conflicts between design and security requirements. The NRC has recently published draft security design considerations for advanced reactors. Once finalized by the NRC, these should be considered in conjunction with the safety design criteria contained in this standard. Security design requirements, including design-basis threats, are design elements to be brought into the plant design process to address the licensing requirements of the national nuclear regulator. In general, both deterministic and risk-informed approaches may be considered in the plant security design process as provided by the national nuclear regulator. It is anticipated that various safety features and inherent safety characteristics together with the use of the risk-informed nuclear safety process described herein will effectively support plant security design.

The risk-informed process embedded in the requirements of this standard is voluntary rather than mandatory. It represents a departure from the approach used by professional communities familiar with traditional, deterministic LWR design processes (e.g., nuclear plant

architect/engineer, nuclear licensing, or risk assessment professionals). This process presents an opportunity to extend traditional use of probabilistic risk assessment as applied to LWRs to MSRs and to incorporate risk insights early in the design process. Beyond designers, regulators, and the risk community, this standard provides a tool for plant operators who use design processes to maintain licensed plant designs. This standard establishes a process that designers can use to incorporate design-specific approaches to nuclear safety.

This is a new standard based upon the growing interest in liquid-fueled MSRs. Much of its structure follows the template developed in ANSI/ANS-54.1-2020, *Nuclear Safety Criteria and Design Process for Sodium Fast Reactor Nuclear Power Plants*. Two LWR counterparts, ANS-51.1/N18.2-1971 (withdrawn), *Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants*, and ANS-52.1-1978 (withdrawn), *Nuclear Safety Criteria for the Design of Stationary Boiling Water Reactor Plants*, were completed and approved much earlier (1971 and 1978, respectively). Those standards were subsequently updated in 1983, adding new risk-based classifications. Revived interest in MSRs, primarily by private organizations, has motivated the development of this new standard. Other, more detailed implementation standards are envisioned for detailed designs.

The ANS-20.2 Working Group was formed in 2015, and a partial draft was prepared by 2018, but at that time the working group decided to hold its completion in abeyance until the new advanced reactor regulatory guides providing broad recommendations for advanced reactor design criteria and risk-informing the design process had reached fruition. When the NRC issued RG 1.232 and RG 1.233, the working group resumed its work and completed the draft standard in 2021, beginning the American Nuclear Society's committee approval process.

Use of this standard does not supersede the responsibility to review and apply the top-level safety criteria of the regulatory authorities in the country in which the user plans to license, build, and operate an MSR. This standard may also be used to support the preparation of an MSR safety analysis report for the purpose of licensing. When used for licensing, this standard does not provide the only basis for establishing the safety and design criteria. The designer must also assess the applicability of the existing body of technical licensing requirements and guidance for nuclear plant licensing. In this regard, the designer determines the applicability, partial applicability, or nonapplicability of these licensing requirements. The designer may use this and other supporting standards to identify additional licensing technical requirements for design and safety aspects not addressed by the existing body of technical licensing requirements and guidance.

This standard might reference documents and other standards that have been superseded or withdrawn at the time the standard is applied. A statement has been included in the references section that provides guidance on the use of references.

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Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants

1 Introduction

1.1 Purpose

The primary purpose of this standard¹⁾ is to provide nuclear safety design criteria for liquid-fuel molten salt reactor (MSR) nuclear power plants (NPPs). The design criteria enable developing reasonable assurance that liquid-fuel MSR NPPs are designed so that they can be operated without undue risk to public health and safety or to the environment. More specifically, the design criteria described in this standard are intended to enable MSR NPPs to achieve the quantitative safety goals of the U.S. Nuclear Regulatory Commission (NRC) [1]²⁾ and the NRC advanced reactor policy statement [2] safety goals.

This standard also provides information about MSR-specific design capabilities and concerns in the form of a nonmandatory appendix, which provides a summary of issues that are unique to MSR designs and should serve as a helpful reference, particularly in understanding the design criteria.

This standard is intended to be useful to both designers and regulators of MSR NPPs. More specifically, it is intended that this standard will be useful to the NRC as it develops specific regulatory guidance for evaluating MSR NPP designs.

1.2 Scope

This standard

- (1) provides design criteria for liquid-fuel MSRs that match the safety intent of the *Code of Federal Regulations* (CFR) Title 10, Part 50, Appendix A [3], general design criteria (GDCs) following an equivalent process to that performed by NRC Regulatory Guide (RG) 1.232 [4] for modular high-temperature gas-cooled reactors (MHTGRs) and sodium-cooled fast reactors (SFRs);
- (2) provides definitions of MSR terminology important for safety evaluation;
- (3) describes distinctive safety considerations for MSRs; and
- (4) provides an MSR-focused description of a risk-informed design process following the methodology described in NEI 18-04 [5] and ANSI/ANS-53.1-2011 (R2021) [6].

¹⁾ The current standard, ANSI/ANS-20.2-2023, is hereinafter referred to as “this standard.”

²⁾ Numbers in brackets refer to corresponding numbers in Sec. 5, “References.”

This standard also provides guidance related to MSR NPP characteristics that will impact the risk-informed selection of licensing-basis events. This standard does not address fissile material separations, plant security, or safeguards issues. Criteria for adequately executing construction and for safely operating and maintaining the nuclear plant are addressed only to the extent that they affect design provisions.

This standard applies to all liquid-fuel MSR NPPs, independent of level of power production and energy end use. It also applies to plant configurations that include more than one reactor unit (modules) on a site. This standard is intended to apply to all liquid salt MSR fuel compositions. The heat transport system is not restricted to a particular configuration, and thus, this standard applies to loop, pool, hybrid, or other arrangements. This standard also pertains to on-site storage of used fuel prior to its removal for recycling or long-term storage. While this standard is not intended to apply to nonpower MSR designs, the content of this standard could assist the design, development, and licensing of research reactors using MSR technology.

1.3 Summary of overall approach used in the standard

1.3.1 Organization

The introductory section (Sec. 1) of this standard includes an overview of the current, NRC-approved, process for developing principal design criteria (PDCs). This standard follows this established pathway as it develops MSR-specific design criteria. The acronyms and definitions section (Sec. 2) provides definitions of terms that have meanings for liquid-fueled MSRs distinctive from those meanings employed by solid-fueled reactors. Given the scope of this standard, all uses of the terms “molten salt reactor” or “MSR” in requirements statements are intended to apply only specifically to liquid-fueled MSRs. Sec. 3 provides design criteria that establish the minimum requirements for the PDCs for an MSR NPP. Sec. 4 indicates that probabilistic, risk-informed methods can be employed as acceptable means to develop MSR NPP PDCs. This standard, however, does not provide probabilistic risk assessment requirements beyond those developed in ANSI/ASME/ANS RA-S-1.4-2021 [7]. This standard includes two nonmandatory, informative appendices. Appendix A provides an overview of the technical differences between liquid salt-fueled nuclear power plants and previously licensed reactors. The material highlights distinctive technical issues that need to be considered when establishing nuclear safety design criteria but does not include any design or performance requirements. Appendix B of this standard provides useful information for consideration if designers wish to use the NRC-endorsed process for developing PDCs or wish to create a risk-informed process of their own for developing PDCs.

1.3.2 Developing PDCs

PDCs for MSRs can be developed using the minimum requirements for NPP PDCs that have been established in 10 CFR 50 Appendix A [3] using the process described in RG 1.232 [4] or, indirectly, using a risk-informed, performance-based process as described in RG 1.233 [8]. Based on a careful consideration of uncertainties that will be required when using either approach, as a conservative measure, additional margins could be initially employed. On the other hand, the advantageous safety characteristics of most MSRs, including low pressure, large margin to boiling, and negative reactivity feedback, makes demonstrating achievement of NRC safety goals easier. A particular challenge for MSRs either in employing quantified probability data for component failure models or in performing accident progression modeling is the limited amount of qualified data available for constructing the models.

1.3.3 Regulatory interface

This standard is intended to provide an acceptable method that supports designing and evaluating the safety performance of MSR NPPs. As with other standards that have been developed by standards development