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NUCLEAR REGULATORY COMMISSION
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TERRESTRIAL ENERGY USA, INC. – FINAL SAFETY EVALUATION REGARDING THE PRINCIPAL DESIGN CRITERIA FOR INTEGRAL MOLTEN SALT REACTOR STRUCTURES, SYSTEMS AND COMPONENTS TOPICAL REPORT REVISION C (EPID L-2021-TOP-0034)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor:	Terrestrial Energy USA, Inc. (TEUSA)
Sponsor Address:	Terrestrial Energy USA 2730 W Tyvola Road, Suite 100 Charlotte, NC 28217
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By letter dated January 17, 2023, Terrestrial Energy USA, Inc. (TEUSA) submitted its topical report (TR), "Principal Design Criteria for IMSR Structures, Systems and Components" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML23025A066) to the U.S. Nuclear Regulatory Commission (NRC or Commission) for NRC staff review. Subsequent Revisions B and C to the TR were submitted on December 29, 2023, and July 19, 2024, respectively (ML24053A168 and ML24204A092). This safety evaluation (SE) is based on Revision C of the TR. TEUSA requested the NRC staff's review and approval of its proposed principal design criteria (PDCs), which are expected to be referenced in future licensing submittals for the TEUSA Integral Molten Salt Reactor (IMSR) design under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

REGULATORY EVALUATION

The regulations under 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," provide general design criteria (GDCs) for water-cooled nuclear power plants similar to those historically licensed by the NRC. Under the provisions of 10 CFR Parts 50 and 52, applicants for a construction permit (CP), operating license (OL), design certification (DC), combined license (COL), standard design approval (SDA), or manufacturing license (ML) must submit PDCs for the proposed facility.

Specifically, the following Commission regulations pertain to the PDCs:

- Paragraph 50.34(a)(3)(i) of 10 CFR, which requires, in part, that applications for a CP include PDCs for the facility. An OL application referencing a CP also includes PDCs.

- Paragraph 52.47(a)(3)(i) of 10 CFR, which requires, in part, that applications for a DC include PDCs for the facility.

- Paragraph 52.79(a)(4)(i) of 10 CFR, which requires, in part, that applications for a COL include PDCs for the facility.

- Paragraph 52.137(a)(3)(i) of 10 CFR, which requires, in part, that applications for an SDA include PDCs for the facility.

- Paragraph 52.157(a) of 10 CFR, which requires that applications for an ML must include PDCs for the reactor to be manufactured.

The regulations under 10 CFR 50.34(a)(3)(i), 10 CFR 52.47(a)(3)(i), 10 CFR 52.79(a)(4)(i), 10 CFR 52.137(a)(3)(i), and 10 CFR 52.157(a), state that 10 CFR Part 50, Appendix A, establishes the minimum requirements for the PDCs for water-cooled nuclear power plants similar in design and location to plants for which CPs have previously been issued by the Commission and provides guidance to applicants in establishing PDCs for other types of nuclear power units. Because the IMSR is not a water-cooled nuclear power plant, PDCs are required, but they do not necessarily align with the minimum requirements in the GDCs in 10 CFR Part 50, Appendix A.

Recognizing that the GDCs in 10 CFR Part 50, Appendix A may not be applicable for non-light-water reactors (non-LWRs), the NRC issued Regulatory Guide (RG) 1.232, “Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors,” which serves as guidance to develop PDCs for non-LWR designs. The NRC also considered the draft guidance in the American National Standards Institute (ANSI)/American Nuclear Society (ANS) ANSI/ANS-20.2-2023, “Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants.” The NRC staff is in the process of reviewing ANSI/ANS-20.2-2023 for requested endorsement (ML24201A044).

TECHNICAL EVALUATION

Introduction

Note: [[ ]] denotes proprietary information.

The PDCs are fundamental to the facility’s design and should be considered in the development of the facility and structures, systems, and components (SSCs) design bases. PDCs aid the NRC staff’s evaluation of other regulations and allow the NRC staff to have reasonable assurance that the design will conform to the design bases with adequate margins for safety.

TEUSA submitted the TR on January 17, 2023 (ML23025A066) and subsequent Revisions B and C on December 29, 2023, and July 19, 2024, respectively (ML24053A168 and ML24204A092), requesting the NRC staff’s review and approval of its design-specific PDCs.

This safety evaluation (SE) is based on Revision C of the TR. As part of the review, the NRC staff also conducted a regulatory audit in accordance with its audit plan (ML24095A305) and documented its findings in an audit report (ML24233A246).

TEUSA states that the purpose of the TR "…is to establish a set of [PDC] for the IMSR [SSCs] that provide important functions in support of the operation and safety of the IMSR facility. Upon approval by the NRC, TEUSA intends for these PDC to be referenced in a subsequent application for [an SDA] for the IMSR Core-unit or in future applications for licenses permitting construction and operation of an IMSR facility." Section IV of the TR further states, "…the IMSR has completed its basic engineering phase so that the system design is reasonably well established. TEUSA acknowledges that some system and component design finalization will be necessary, however, TEUSA believes that the PDC discussed [in the TR] will effectively represent the key systems and components of the IMSR that will be used to establish that the IMSR design will provide reasonable assurance of adequate protection of public health and safety."

As the GDCs in 10 CFR Part 50, Appendix A function as guidance (not regulatory requirements for non-LWRs), TEUSA developed PDCs for the IMSR design based on the guidance in RG 1.232. Guidance in RG 1.232 provides a general set of advanced reactor design criteria (ARDCs) and also addresses design criteria for two specific non-LWR designs, the Sodium-Cooled Fast Reactor (SFR) and the Modular High-Temperature Gas-Cooled Reactor (MHTGR). In Section IV of the TR, TEUSA notes that, as stated in RG 1.232, molten salt reactors (MSRs) that use liquid fuel may need to develop new PDCs for liquid fuel and systems to support its design. Together with a comparison to RG 1.232, justification has been provided for each of the PDCs proposed in the TR. TEUSA also considered the draft guidance in the American National Standards Institute/American Nuclear Society ANSI/ANS-20.2-2023, to develop PDCs for the design.

IMSR Design Features

The IMSR is a graphite-moderated MSR that uses a fluoride fuel salt. The power plant consists of two reactor auxiliary buildings (RABs) that produce a total of 884 MW_{th}, (442 MW_{th} per core-unit) for about 390 MW_e (195 MW_e per steam turbine) of net electric output. The IMSR includes an adjacent steam plant and turbine buildings for each RAB. Each steam plant and turbine building contain non-nuclear-grade, industry-standard power equipment. The IMSR fuel salt uses low enriched uranium, in a liquid form, not a solid form. The IMSR uranium fuel in the form of uranium tetrafluoride (UF_4), is . Containment consists of the that houses radioactive materials. This includes radioactive materials (irradiated fuel salt and off-gases) in the core-unit, fuel salt storage tanks (FSSTs), gas holding tanks, and connecting piping. The steam plant and the associated buildings have no safety function for the IMSR nuclear power plant and are therefore located outside of the protected area. IMSR employs a conventional industrial electrical generator system with superheated and reheated steam capabilities, as well as multi-stage feedwater heating and a condenser unit. The description of the design features was included in this safety evaluation report (SER) for information, but the staff makes no findings concerning the adequacy of these features.

Process for Developing PDCs

TEUSA detailed its proposed PDCs for the IMSR in the TR,

TEUSA requests approval for the proposed PDCs without the finalized design. The TR states that TEUSA acknowledges that some system and component design finalization will be necessary. If continued development results in changes to design features, a revision to the proposed PDC described in the TR may be necessary, and therefore, the NRC staff restricts the use of the TR as discussed in the Limitations and Conditions 1 through 4 in this SER.

As stated in the regulatory evaluation section of this SE, an applicant for a CP, DC, COL, SDA, or ML under 10 CFR Part 50 or Part 52 is required to include PDCs for the facility. Section V of the TR describes the process used by the applicant to develop the PDCs for the IMSR. The applicant elected to use RG 1.232 and the draft ANSI/ANS standard to develop its PDCs. The applicant relied on RG 1.232 to develop its design-specific PDCs. The IMSR in RG 1.232, but it does . Ultimately, TEUSA used the and adapted them to the IMSR design, as applicable. The NRC staff has not endorsed the draft ANSI/ANS standard and makes no findings with respect to the standard.

IMSR PDCs Organization

TEUSA provided the proposed IMSR PDCs in a format in RG 1.232, as follows:

- Section I - Overall Requirements (Criteria 1-5)
- Section II - Multiple Barriers (Criteria 10-19)
- Section III - Reactivity Control (Criteria 20-29)
- Section IV - Heat Transport Systems (Criteria 30-46)
- Section V - Reactor Containment (Criteria 50-57)
- Section VI - Fuel and Radioactivity Control (Criteria 60-64)
- Section VII - Additional (Criteria 70-79)

NRC Staff's Evaluation of IMSR PDCs

Sections VI and VII of the TR provide the justification for TEUSA's PDC selection. When TEUSA deviates from the verbatim guidance in RG 1.232, a rationale is provided describing how the changes relate to the safety basis of the IMSR. Similarly, when TEUSA elects to add or not utilize a PDC in RG 1.232, it includes a justification from a safety perspective for the addition or omission.

Applicants and licensees may voluntarily use the guidance in RG 1.232 to demonstrate compliance with the underlying NRC regulations regarding PDCs. As stated in RG 1.232, different methods or solutions may be deemed acceptable if a sufficient basis and supporting information is provided for the NRC staff to verify that the proposed alternative demonstrates compliance with the relevant NRC regulations.

NRC Staff Evaluation of Specific IMSR Principal Design Criteria

PDC With No Changes

In the following proposed PDCs:

The NRC staff finds that these PDCs are sufficiently broad to apply to the IMSR, and the rationale for the underlying safety basis documented in RG 1.232 remains applicable. As such, the NRC staff finds these PDCs to be acceptable.

PDCs With Minor Terminology Changes to RG 1.232 DC

TEUSA changes words or terms from

The NRC staff finds that these changes are applicable to the IMSR design, and that the rationale for the underlying safety basis documented in RG 1.232 remains applicable. As such, the NRC staff finds the proposed changes to the PDCs acceptable. Changes to these PDCs other than terminology are addressed separately in the SER.

In TEUSA-4, TEUSA proposes

therefore the staff finds TEUSA-4 to be acceptable.

PDCs With Substantive Technical Changes

For the following PDCs, TEUSA made what staff determined to be substantive technical changes. These are changes that alter the rationale for the safety basis for the corresponding

In TEUSA-10, TEUSA proposed changes to the corresponding

In TEUSA-34, TEUSA-35, and TEUSA-78, TEUSA proposed the following changes to the corresponding from RG 1.232, following the proposed changes in TEUSA-10: in TEUSA-34, replacing

in TEUSA-35, replacing

in TEUSA-78,

replacing

Consequently, the NRC staff finds TEUSA-34, TEUSA-35, and TEUSA-78 acceptable, contingent upon the Limitation and Condition 2 listed below in this SER.

In TEUSA-12, TEUSA proposed changes to the corresponding

The NRC staff finds that the rationale for the underlying safety basis documented in RG 1.232 remains valid. The NRC staff imposed Limitation and Condition 3 listed below in this SER to ensure that a detection system has an appropriate safety classification consistent with Institute of Electrical and Electronics Engineers Standard (IEEE Std) 603-1991, “Criteria for Safety Systems for Nuclear Power Generating Stations,” which is endorsed by RG 1.153, Revision 1, “Criteria for Safety Systems,” including the correction sheet, dated January 30, 1995.

In TEUSA-19, TEUSA proposed changes to the corresponding

TEUSA modified the contents of TEUSA-20 through TEUSA-29, because the IMSR

In TEUSA-20 through TESUA-25, TEUSA proposed that

In TEUSA-5, TEUSA proposed changes to the corresponding

] The NRC staff’s evaluation of a safe state is contingent on the NRC staff’s findings for TEUSA-26.

Based on this evaluation, the NRC staff finds TEUSA-5 to be acceptable, contingent upon Limitations and Condition 4 listed below in this SER.

In TEUSA-26, TEUSA proposed changes to the corresponding

Regarding TEUSA's proposed safe state, the NRC staff considered, in addition to RG 1.232, the relevant policy documented in prior SECY papers and the associated NRC staff requirements memoranda. This includes: (1) an evaluation of safe shutdown in the context of regulatory treatment of non-safety systems in passive plant designs, (2) the NRC staff's approach for addressing a potential return to criticality in a recently approved small, modular reactor design, and (3) the 2008 Policy Statement on the Regulation of Advanced Reactors (ML082750370).

In SECY-94-084, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs," the NRC staff evaluated an industry proposal to define a safe stable shutdown condition for passive, water-cooled reactors as one where the reactor coolant system was cooled to 215.6 degrees Celsius (°C) (420.08 degrees Fahrenheit (°F)) (ML003708068). SECY-94-084 describes a safe shutdown condition as providing: (1) reactor subcriticality, (2) decay heat removal, and (3) radioactive materials containment. RG 1.232 ARDC 26 (1) clearly defines that reactor shutdown at any time during the transient is the performance criterion associated with the underlying safety basis. The definition of "safety-related" in 10 CFR 50.2, "Definitions," also relates to the requirement of shutting down a reactor, which, as discussed above, requires subcriticality. The NRC staff notes that ARDC 26 allows for a return to power during a postulated accident consistent with the current licensing basis of some existing pressurized water reactors (PWRs) if sufficient heat removal capability exists (e.g., PWR main steam line break accident), but ARDC 26 (1) precludes a return to power during an AOO. The NRC staff notes that subcritical shutdown may not be needed to reach a safe and stable state for some non-LWRs, and therefore which is identical to ARDC 26) as written in RG 1.232, does not strictly apply to the IMSR.

In SECY-18-0099, "NuScale Power Exemption Request from 10 CFR Part 50, Appendix A, General Design Criterion 27, 'Combined Reactivity Control Systems Capability,'" the NRC staff discussed how it would address the potential for the NuScale reactor to return to a critical condition beyond the short-term transient portion of some postulated accidents (ML18065A431),

The NRC staff's evaluation of NuScale's condition is discussed in Section 15.0.6 of the final safety evaluation report for the NuScale US600 design certification (ML20205L408). The NRC staff applied three criteria: (1) the reactor design was required to provide sufficient thermal margin such that a return to power would not result in the failure of a fission product barrier, (2) the conditions leading to a return to criticality were required not to be expected during the lifetime of a power module, and (3) the return to criticality was required not to adversely erode the margin between the Commission's goals for new reactor designs related to estimated frequencies of core damage or large releases and those that had been calculated for the NuScale US600 design (ML20205L408). The NRC staff further clarified that both the acceptability of the design and of granting an exemption for NuScale would be based on the merits of the safety case.

Unlike NuScale, TEUSA would not need an exemption from any GDCs. As stated in RG 1.232, the GDCs in 10 CFR 50, Appendix A are not regulatory requirements for non-LWR designs; therefore, non-LWR applicants would not need to request an exemption from the GDC in 10 CFR Part 50 when proposing PDCs for a specific design.

In the Commission's 2008 Policy Statement on the Regulation of Advanced Reactors, the final policy statement stated the Commission's expectation that advanced reactors would provide enhanced margins of safety and/or use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions (ML082750370). The Commission included attributes that could assist in establishing the acceptability of a proposed reactor design, and therefore should be considered in advanced designs, including, in part, highly reliable and less complex shutdown and decay heat removal systems; longer system time constants; and simplified safety systems that, where possible, reduce required operator actions, equipment subjected to severe environmental conditions, and components needed for maintaining safe shutdown conditions. TEUSA's

Given the preliminary nature of the IMSR design, NRC staff makes no determination concerning the means of reactor control that will be relied upon to conform with TEUSA-26; however, TEUSA's approach for conformance appears reasonable given the preliminary information. TEUSA proposes to

While other applicants have typically credited control rods as the primary means of reactivity control to satisfy GDC 26 or an equivalent PDC, TEUSA's approach is not precluded by RG 1.232, which acknowledges that, for advanced reactors, inherent feedback mechanisms may be relied upon to shut down the reactor. The rationale provided in RG 1.232, however, reflects the NRC staff's view that the means used to satisfy ARDC 26, subpart 1 is classified as safety-related.

While the SDM is credited as an independent means for controlling reactivity distinct from the inherent reactivity feedback, the SDM itself is not safety-related but is important to safety and is relied upon to remain available for plant operator action during normal operation including AOOs and DBAs. The staff therefore find TEUSA-26 acceptable subject to Limitation and Condition 4.

TEUSA proposed no criteria corresponding to . TEUSA stated that t

TEUSA-41, -42, and -43

, but it does not employ a containment atmosphere cleanup system. The IMSR is an integral reactor so no fuel salt discharge from the reactor to the containment should occur for AOOs and DBAs. The off-gas system is not connected to the containment atmosphere and is not available for cleanup of the containment atmosphere.

, this is not its intended function during postulated events. The liquid fuel salt also retains fission products. These features minimize fission gas release to the containment following postulated accidents. Additionally, TEUSA stated that there is no need to control the concentration of other substances in the containment atmosphere because hydrogen and other non-condensable gases will not be generated following postulated accidents. The NRC staff finds the proposed change from design criteria in RG 1.232 to be acceptable because: (1) TEUSA confirms that the release of any radionuclides that may have escaped from the reactor vessel and entered the containment areas should be negligible for AOOs and DBAs, (2) TEUSA confirms that hydrogen and other non-condensable gases will not be generated following postulated accidents, and (3) containment isolation is possible, according to the design.

In TEUSA-79, TEUSA proposed

While TEUSA did not propose

LIMITATIONS AND CONDITIONS

The NRC staff imposes the following limitations and conditions, which must be addressed in a licensing application referencing this TR:

1. The approval for the proposed PDCs is based on the IMSR preliminary design at the time of the TR submittal. Further design changes could necessitate revisions to the proposed PDCs described in the TR. Therefore, future licensing applicants referencing the TR must confirm that the PDCs in this TR remain valid for its design. In addition, if additional or revised PDCs are identified that fall outside the scope of those approved in this SER, they will be subject to further NRC staff review.

2. Applicants adopting TEUSA-10 must:

3. Applicants referencing this TR must justify the proposed approach in TEUSA-12 and TEUSA-20 through TEUSA-25, specifically demonstrating that the SSC classification is appropriate and ny

4. Applicants referencing this TR must address the following considerations to justify the proposed approach to TEUSA-26, specifically demonstrating that the SSC classification is appropriate and

CONCLUSION

Based on the above evaluation, the NRC staff concludes that TEUSA has provided a sufficient set of PDCs for establishing requirements for the IMSR design, subject to the limitations and conditions of this SER. The proposed PDCs meet the underlying purpose and technical rationale of the ARDC in RG 1.232. Subject to the limitations and conditions of this SER, these PDCs establish the necessary design, fabrication, construction, testing, and performance requirements for safety significant SSCs to provide reasonable assurance that an IMSR could be operated without undue risk to the health and safety of the public.

REFERENCES

1. U.S. Nuclear Regulatory Commission, “Guidance for Developing Principal Design Criteria for Non-Light Water Reactors,” RG 1.232, Revision 0. ML18058B961.

2. U.S. Nuclear Regulatory Commission, “Functional Containment Performance Criteria for Non Light-Water-Reactors,” SECY-18-0096, dated October 16, 2018. ML18114A546.

3. U.S. Nuclear Regulatory Commission, “Staff Requirements- SECY-18-0096 Functional Containment Performance Criteria for Non-Light-Water-Reactors,” dated December 4, 2018. ML18338A502.

4. U.S. Nuclear Regulatory Commission, “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs,” SECY-94-084, dated March 28, 1994. ML003708068.

5. U.S. Nuclear Regulatory Commission, “Principal Design Criteria for IMSR Structures, Systems and Components TEUSA Topical Report – Document #TR230117.” ML23025A066.

6. Chapter 15 of the Final Safety Evaluation Report, “Transient and Accident Analyses,” of the NuScale Power, LLC, Design Certification Application, Part 2, “Final Safety Analysis Report.” ML20205L408.

7. U.S. Nuclear Regulatory Commission, “IMSR Core-unit Definition, Applicable Structures, Systems, and Components,” Revision 1, dated May 2022. ML22138A340.

8. ANS 20.2, “Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants.” (DRAFT)

Principal Contributors: Matthew Gordon, NRR
Christopher Adams, NRR
Joseph Ashcraft, NRR
Hanh Phan, NRR
Adrian Muniz, NRR
Michelle Vega Rodriguez, NRR
Lucieann Vechioli Feliciano, NRR
Benjamin Parks, NRR