UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

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U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: DRAFT SAFETY EVALUATION OF THE TERRAPOWER TOPICAL REPORT, "PLUME EXPOSURE PATHWAY EMERGENCY PLANNING ZONE METHODOLOGY," REVISION 3

Dear Dr. Gavrilas:

During the 720th meeting of the Advisory Committee on Reactor Safeguards, November 6 through 8, 2024, we completed our review of the TerraPower Topical Report (TR), "Plume Exposure Pathway Emergency Planning Zone Methodology," Revision 3, and the associated Nuclear Regulatory Commission (NRC) staff safety evaluation report (SER). Our TerraPower Natrium Design-Centered Subcommittee reviewed this matter on September 19, 2024. During these meetings, we had the benefit of discussions with the staff and representatives of TerraPower. We also had the benefit of the referenced documents. Additionally, our Accident Analysis subcommittee received an information briefing from NRC staff related to criteria for selection of accident scenarios to determine emergency planning zone (EPZ) boundaries on October 1, 2024.

CONCLUSIONS AND RECOMMENDATIONS

1. The proposed methodology is expected to result in an EPZ size that is consistent with the principles historically used as part of the emergency preparedness (EP) framework.

2. The TR proposal to assess potential cliff-edge effects for EPZ sizing only when accident event sequence frequency exceeds a threshold ($1x10^{-8}$/plant-year) is not aligned with more recent regulatory guidance provided for the risk-informed, performance-based, technology inclusive licensing methodology for non-light water reactors (non-LWRs). The EPZ regulatory guidance recommends retention of event sequences below a frequency cutoff (for Natrium this value is $1x10^{-7}$/plant-year) when assessing for cliff-edge effects. However, there is no specific guidance on how to further screen the large number of sequences that must be considered in practice. Given this lack of specificity, the threshold used in the TR should have been justified.

3. The SER should not be issued until the rationale for the use of the frequency threshold when assessing the potential for cliff-edge effects is addressed, as discussed above.

4. The committee continues to observe that additional clarifying guidance is warranted regarding selection criteria for the spectrum of events to consider for determination of the source term that is to be applied for EPZ sizing.

BACKGROUND

Requirements for EP

Nuclear power plant EP regulatory requirements were developed to provide reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency. These are codified under Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.47, "Emergency Plans," and 10 CFR Part 50, Appendix E, "Emergency Planning and Preparedness for Production and Utilization Facilities." Generally, the size of the EPZs for the current generation of large light water reactors is defined by 1) a plume exposure pathway EPZ area of about 10 miles in radius and 2) an ingestion pathway EPZ area of about 50 miles in radius. The size of EPZs surrounding a particular nuclear power plant may also be affected by such conditions as demography, topography, land characteristics, access routes, and jurisdictional boundaries.

The basis for sizing of EPZs was updated in 2023 to allow an alternative EP framework for small modular reactors (SMRs) and other new technologies (ONTs), as described in a Federal Register Notice dated November 16, 2023 (88 FR 80050). These new alternative EP requirements and implementing guidance in Regulatory Guide (RG) 1.242 adopt a performance-based, technology-inclusive, risk-informed, and consequence-oriented approach that: (1) recognizes advances in design and technology advancements embedded in design features; (2) credits safety enhancements in evolutionary and passive systems; and (3) credits the potential benefits of smaller sized reactors and non-LWRs associated with postulated accidents, including slower transient response times, and relatively small and slow release of fission products. This revision allows for a scalable EPZ size instead of a predetermined size such as 10 miles, while continuing to meet the EP objective of dose savings for a spectrum of accidents, including beyond design basis accidents, that could produce offsite doses in excess of protective action guides (PAGs).

The alternative EP framework defines the plume exposure pathway EPZ for SMRs and ONTs as the area within which PAGs would be met for a 96-hour period following an accident[1]. The framework states that this criterion should consider "accident likelihood and source term, timing of the accident sequence, and meteorology." Consideration of "accident likelihood" is further addressed in RG 1.242. This regulatory guide observes that, historically, the plume exposure pathway EPZ was sized such that PAGs are not exceeded for all design basis accidents and most severe accident scenarios. RG 1.242 also states, "*for the worst core melt sequences, immediate life-threatening doses would generally not occur outside the EPZ.*" Appendix B of RG 1.242 notes that determination of which accident scenarios are assessed against the PAGs and

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[1] 10 CFR section 50.33(g)(2)(i)) states the following definition applicable to SMRs and ONTs: "*The plume exposure pathway EPZ is the area within which: (A) Public dose, as defined in § 20.1003 of this chapter, is projected to exceed 10 mSv (1 rem) total effective dose equivalent over 96 hours from the release of radioactive materials from the facility considering accident likelihood and source term, timing of the accident sequence, and meteorology; and (B) Pre-determined, prompt protective measures are necessary.*"

which are assessed against immediate life-threatening doses may be done using accident scenario frequencies from a probabilistic risk assessment (PRA). In such cases, the regulatory guide states that a technical basis needs to be provided, with the following guidance:

"*The categorization of accidents, including any category bounds based on frequency (including consideration of uncertainty), should be explained. If based on PRA, the use of a low-frequency "cutoff" should consider uncertainty. The PRA results should retain event sequences with frequencies below the "cutoff," and analysts should use them to confirm that there are no cliff edge effects and that there is adequate defense in depth.*"

Natrium EPZ Methodology

The TerraPower Natrium TR is the first such report to be submitted in accordance with the published alternative EP framework as supported by RG 1.242. The TR was revised in November 2023 to align with the alternative framework. It describes a methodology to determine the size of the plume exposure pathway EPZ for Natrium plant sites. The ingestion pathway is not addressed in this methodology, as this aspect of EP is largely site-specific.

For non-seismic scenarios, the TR methodology sets the plume exposure pathway EPZ boundary to the larger of the two distances determined based on accident frequency:

- All accident scenario event sequences with a mean frequency greater than $1x10^{-6}$/plant-year will be assessed to determine the distance at which the 10 CFR 50.33(g)(2)(i) criterion of 1 Rem total effective dose equivalent (TEDE) is met for a 96-hour period following the accident. This corresponds to all design basis accidents and most severe accident scenarios as described in RG 1.242.

- All accident scenario event sequences with a mean frequency greater than $1x10^{-7}$/plant-year will be assessed to determine the distance at which a 200 Rem criterion is met for the 24-hour period following the accident. The methodology uses 200 Rem to the red bone marrow, not TEDE, as a conservative surrogate for estimating the potential for immediate life-threatening doses. This corresponds to the "worst core melt sequences" as described in RG 1.242.

To account for uncertainties, the TR states that all non-seismic accident scenario event sequences with mean frequency between $1x10^{-8}$/plant-year and $1x10^{-7}$/plant-year will be assessed as follows: (1) accident scenario event sequences with upper 95th percentile frequencies that exceed $1x10^{-7}$/plant-year will be included in the plume exposure pathway EPZ assessment; and (2) all accident scenario event sequences in this frequency range will be evaluated for cliff-edge effects. As clarified in Revision 3 of the TR, accident scenario event sequences with mean frequency below $1x10^{-8}$/plant-year will be screened from further consideration. The use of a frequency threshold for screening of sequences for cliff-edge effects determination is not addressed in regulatory guidance.

For seismic scenarios, the methodology uses a peak ground acceleration (PGA) value aligned to achieve at least two times the Ground Motion Response Spectrum (GMRS) resulting from a site-specific scoping level seismic PRA (SPRA). However, an upper bound PGA of 1.0 times gravitational acceleration (1.0 g) will be utilized to acknowledge the limitations of the PRA and uncertainties associated with availability of local and state emergency response infrastructure at large ground motions. The selected seismic scenario accounts for the phenomena and the consequences, considering uncertainty and cliff-edge effects. Uncertainty associated with the

confidence in the site-specific seismic characteristics will be addressed within the SPRA and specific seismic analyses.

DISCUSSION

NRC Staff Draft SER

The draft SER endorses the TR methodology as discussed above, subject to six Limitations and Conditions (L&Cs). Most of the L&Cs relate to the completeness of the PRA, requiring (for example) that any exceptions to regulatory guidance be documented and justified. The draft SER was revised after our September 19, 2024, TerraPower Natrium Design-Centered subcommittee meeting to resolve some of the questions that we asked during the meeting. Specifically:

- An L&C was added for seismic scenarios to require an applicant using the TR to assure that use of the 1.0 g upper bound for seismic acceleration is conservative. This L&C addresses the potential that the resulting seismic accelerations may not be conservative if the calculated peak ground accelerations were to approach 1.0 g.

- An L&C was revised to delete reference to applicable hazards and modes *"not covered by the non-LWR PRA standard.*" This revision eliminates confusion as to why relevant hazards and modes might be screened out per the non-LWR PRA standard, given that a PRA performed per the standard should include all relevant hazards.

We agree with these revisions.

Cliff-Edge Effects

The TR proposal to assess potential cliff-edge effects for EPZ sizing only when accident event sequence frequency exceeds a threshold ($1x10^{-8}$/plant-year) is not aligned with more recent regulatory guidance provided for the risk-informed, performance-based, technology inclusive licensing methodology for non-LWRs:

- RG 1.242 states the following relative to cliff-edge effects: "*The PRA results should retain event sequences with frequencies below the "cutoff," and analysts should use them to confirm that there are no cliff edge effects and that there is adequate defense in depth.*" This guidance is consistent with guidance in NEI 18-04 ("Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development"); for example, Task 4 of the Licensing Basis Event (LBE) selection process states: "*Event sequences with upper 95th percentile frequencies less than $5x10^{-7}$/plant-year are retained in the PRA results and used to confirm that there are no cliff-edge effects. They are also taken into account in the risk-informed and performance-based (RIPB) evaluation of defense-in-depth in Task 7e.*" Neither of these statements invoke a lower frequency threshold for assessment of cliff-edge effects.

- Use of PRA results in the assessment of cliff-edge effects is part of the strategy for determining if there is an analyzed (or not even modeled) scenario that could have

risk-significant consequences if any parameter changes beyond what is modeled.[2] Searching for such scenarios is part of the consideration of defense-in-depth. The intent is to use the PRA model to help assure that all applicable hazards, and the structures, systems, and components included to mitigate them, are considered when evaluating whether the plant design adequately mitigates cliff-edge effects.

- The TR defines a frequency threshold ($1x10^{-8}$/plant-year) below which cliff-edge effects are not considered for EPZ sizing. Use of such a threshold is not addressed in the regulatory guidance. Applying this threshold before searching for sequences that might exhibit cliff-edge effects could limit the effectiveness of the search for such scenarios.[3] During our meeting on November 7, 2024, TerraPower representatives stated the cliff-edge evaluation done as part of the licensing modernization project (LMP) safety assessment does not use this lower frequency threshold. It is not evident why low-frequency events that are assessed as part of the overall safety evaluation are not considered during EPZ sizing, particularly because the EPZ is part of the last layer of defense and is intended to aid in mitigating low frequency events. Application of a lower screening threshold below which cliff-edge effects do not need to be assessed for EPZ sizing requires further justification.

SUMMARY

The proposed methodology is expected to result in an EPZ size that is consistent with the principles historically used as part of the emergency preparedness (EP) framework. The TR proposal to assess potential cliff-edge effects for EPZ sizing only when accident event sequence frequency exceeds a threshold ($1x10^{-8}$/plant-year) is not aligned with more recent regulatory guidance provided for the risk-informed, performance-based, technology inclusive licensing methodology for non-light water reactors (non-LWRs). The EPZ regulatory guidance recommends retention of event sequences below a frequency cutoff (for Natrium this value is $1x10^{-7}$/plant-year) when assessing for cliff-edge effects. However, there is no specific guidance on how to further screen the large number of sequences that must be considered in practice. Given this lack of specificity, the threshold used in the TR should have been justified. The SER should not be issued until the rationale for the use of the frequency threshold when assessing the potential for cliff-edge effects is addressed.

The committee continues to observe that additional clarifying guidance is warranted regarding selection criteria for the spectrum of events to consider for determination of the source term that is to be applied for EPZ sizing. For example, our review pointed out that the regulatory guidance

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[2] See INL/EXT-20-60392, section 5.3.7: "*The LMP methodology does not specifically identify whether a specific non-LWR design exhibits cliff edge effects, except that to the extent that they exist, they may be apparent in the results of the PRA which may provide risk insights for event sequences below the cutoff for Beyond Design Basis Events at 5×10^{-7} per plant-year. The existence or lack thereof of cliff edge effects is really part of the safety characteristics of a nuclear plant and not merely a property of the PRA models.*"

[3] As an example, the Risk Achievement Worth (RAW) parameter, which is intended to determine sensitivity to failure of single events modeled in the PRA, may not effectively identify such scenarios if the PRA model is limited before calculating RAW.

in both RGs 1.233 and 1.242 could be enhanced to support more efficient reviews (i.e., a common understanding between the applicant and staff) on the role of cliff-edge effects. We encourage the staff to apply lessons-learned from this TR review and other industry engagements to clarify the guidance.

Sincerely,

Signed by Kirchner, Walter on 11/26/24

Walter L. Kirchner
Chair

REFERENCES

1. U. S. Nuclear Regulatory Commission, "TerraPower, LLC – Revised Draft Safety Evaluation of Natrium Topical Report NAT-3056, Plume Exposure Pathway Emergency Planning Zone Sizing Methodology, Revision 3 (EPID L-2023-TOP-0024/CAC 000431)," November 2024 (Agencywide Documents Access and Management System (ADAMS) Accession Number ML24325A377).

2. U. S. Nuclear Regulatory Commission, "Terrapower, LLC – Safety Evaluation Of Natrium Topical Report Nat-3056, Plume Exposure Pathway Emergency Planning Zone Sizing Methodology, Revision 1 (EPID L-2023-TOP-0024/CAC 000431)," August 30, 2024 (ADAMS) Accession Number ML24242A101)."

3. TerraPower, LLC., "Transmittal of TerraPower Plume Exposure Pathway Emergency Planning Zone Methodology Topical Report, NAT-3056 Revision 3," October 30, 2024 (ADAMS Accession No. ML24304B034).

4. Title 10 of the *Code of Federal Regulations* Part 50 - Domestic Licensing of Production and Utilization Facilities (https://www.ecfr.gov/current/title-10/chapter-I/part-50).

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.242, "Performance-Based Emergency Preparedness For Small Modular Reactors, Non-Light-Water Reactors, And Non-Power Production Or Utilization Facilities," Revision 0, November 2023 (ADAMS Accession No. ML23226A036).

6. U.S. Federal Register, Notice Number 88 FR 80050, "Emergency Preparedness for Small Modular Reactors and Other New Technologies," November 16, 2023 (https://www.federalregister.gov/d/2023-25163)

7. U.S. Nuclear Regulatory Commission, NUREG 0396, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants," December 1978 (ADAMS Accession No. ML051390356).

8. Nuclear Energy Institute, NEI 18-04, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development," Revision 1, August 2019 (ADAMS Accession No. ML19241A472).

9. Wayne L Moe, Amir Afzali, Idaho National Laboratory, INL/EXT-20-60392-Revision-0, “Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors: LMP Lessons Learned, Best Practices, and Frequently Asked Questions,” March 2020 (https://www.osti.gov/servlets/purl/1700534).

10. ASME/ANS Standard, ASME/ANS RA-S-1.4-2021, “Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants,” February 8, 2021.

11. U.S. Nuclear Regulatory Commission, NUREG 1860, “Feasibility Study for Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing,” December 2007 (ADAMS Accession No. ML080440170).

12. U.S. Nuclear Regulatory Commission, Advisory Committee on Reactor Safeguards, “Draft Final Rule, ‘Emergency Preparedness for Small Modular Reactors and Others New Technologies’,” November 16, 2021 (ADAMS Accession No. ML21316A252).

13. US. Nuclear Regulatory Commission, “In Response to Draft Final Rule, ‘Emergency Preparedness for Small Modular Reactors and Others New Technologies’,” December 17, 2021 (ADAMS Accession No. ML21322A003).

14. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.233, “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,” June 2020 (ADAMS Accession No. ML20091L698).

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