UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

TERRAPOWER, LLC – 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)

SPONSOR AND SUBMITTAL INFORMATION

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Project No.: 99902100

Submittal Date: March 20, 2023

Submittal Agencywide Documents Access and Management System (ADAMS) Accession Nos.: ML23080A045, ML23321A036, ML24304B034

Brief Description of the Topical Report: By letter dated March 20, 2023, TerraPower, LLC (TerraPower) submitted a Topical Report (TR) entitled, "Plume Exposure Pathway Emergency Planning Zone Methodology," Revision 0 (ML23080A045), for the U.S. Nuclear Regulatory Commission (NRC) staff's review. By email dated June 12, 2023, the NRC staff informed TerraPower that the TR provided sufficient information for the NRC staff to begin its detailed technical review (ML23158A203). From August 11, 2023, through October 17, 2023, the NRC staff conducted an audit to gain a detailed understanding of the TR methodology and identify any additional information that required docketing to support the NRC staff's safety evaluation (SE) for the TR (ML23199A317). By letter dated November 16, 2023, TerraPower submitted Revision 1 of the TR (ML23321A036) that addressed items discussed during the NRC staff audit and other minor editorial revisions. The audit report summarizing the NRC staff's observations was issued on January 8, 2024 (ML24008A057). By letter dated October 30, 2024, TerraPower submitted Revision 3 of the TR (ML24304B034) to provide further insight into the description of the plume exposure pathway emergency planning zone (EPZ) sizing methodology.

This SE and the staff's determinations are based on Revision 3 of the TR. The TR describes TerraPower's methodology to be used to determine the plume exposure pathway EPZ for the proposed Natrium reactor design. TerraPower requested the NRC staff's review and approval on the plume exposure pathway EPZ sizing methodology TR.

For background, TerraPower's overall licensing approach for the Natrium reactor design follows the Licensing Modernization Project (LMP) methodology described in Nuclear Energy Institute (NEI) 18-04, Revision 1, "Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development" (ML19241A472). Regulatory Guide

(RG) 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,” Revision 0 (ML20091L698) endorses the LMP methodology described in NEI 18-04. TerraPower based the methodology described in this TR on the proposed requirements in SECY-22-0001, “Final Rule: Emergency Preparedness for Small Modular Reactors and Other New Technologies” and a draft version of RG 1.242, “Performance-Based Emergency Preparedness for Small Modular Reactors, Non-Light-Water Reactors, and Non-Power Production or Utilization Facilities” published only to support an NRC staff meeting with the Advisory Committee on Reactor Safeguards (ACRS) (ML21285A035). The final version of RG 1.242, Revision 0, (ML23226A036) was issued in November 2023 to support the final rule and did not differ in content from the draft version with respect to guidance relevant to review of the TR EPZ sizing methodology.

REGULATORY EVALUATION

NRC regulatory requirements for nuclear power facility emergency planning, including the requirement for a plume exposure pathway EPZ, are given in Title 10 of the *Code of Federal Regulation* (10 CFR) 50.47, “Emergency plans” and 10 CFR 50, appendix E, “Emergency Planning and Preparedness for Production and Utilization Facilities.”

Sections 50.33(g)(1) and 50.47(c)(2), describe the requirements for the size of EPZs for a nuclear power reactor as follows:

> Generally, the plume exposure pathway EPZ for nuclear power reactors shall consist of an area with about 10 miles (16 km) in radius and the ingestion pathway EPZ shall consist of an area with about 50 miles (80 km) in radius. The exact size and configuration of the EPZs surrounding a particular nuclear power reactor shall be determined in relation to the local emergency response needs and capabilities as they are affected by such conditions as demography, topography, land characteristics, access routes, and jurisdictional boundaries. The size of the EPZs also may be determined on a case-by-case basis for gas-cooled reactors and for reactors with an authorized power level less than 250 MW thermal. The plans for the ingestion pathway shall focus on such actions as are appropriate to protect the food ingestion pathway.

Alternative emergency preparedness (EP) requirements for small modular reactors (SMRs) and other new technologies (ONTs) are given in 10 CFR 50.160, “Emergency preparedness for small modular reactors, non-light-reactors, and non-power production or utilization facilities,” also referred to as EP for SMRs and ONTs rule (88 FR 80050). This rule includes a scalable approach to determining the size of the plume exposure pathway EPZ for SMRs and ONTs that is performance-based, consequence-oriented, risk-informed, and technology-inclusive. For facility applications complying with 10 CFR 50.160, 10 CFR 50.33(g)(2) requires that the application must include the analysis used to determine whether plume exposure pathway EPZ criteria in 10 CFR 50.33(g)(2)(i)(A) and (B) are met, and if so, the size of the plume exposure pathway EPZ.

Under 10 CFR 50.33(g)(2)(i) the plume exposure pathway EPZ is the area within which:

> (A) Public dose, as defined in § 20.1003 [“Definitions”] of this chapter [Chapter I to Title 10] is projected to exceed 10 mSv (1 rem) total effective dose equivalent [TEDE] 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.

RG 1.242, Revision 0, “Performance-Based Emergency Preparedness for Small Modular Reactors, Non-Light-Water Reactors, and Non-Power Production or Utilization Facilities” (ML23226A036) provides guidance on consequence analyses to aid in facility-specific plume exposure pathway EPZ size determination for facility applications complying with 10 CFR 50.160.

NUREG-0396, “Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants” (ML051390356), provides the technical basis for the requirement for a 10-mile plume exposure pathway EPZ in 10 CFR 50.33(g)(1) and 50.47(c)(2). The regulatory basis for the EP for SMRs and ONTs rule considered the dose assessment methodologies that informed NUREG-0396 to offer an EPZ size determination process that is consistent with the philosophy in NUREG-0396, as discussed in the *Federal Register* (FR) notice for the final 10 CFR 50.160 rule (88 FR 80058). RG 1.242, appendix A, “General Methodology for Establishing Plume Exposure Pathway Emergency Planning Zone Size,” describes an acceptable approach to meet the EPZ sizing requirements for 10 CFR 50.160 that was generalized from the consequence assessment that informed NUREG-0396.

The emergency plan supports planning and preparedness to enable emergency response organizations and State and local governments to take necessary actions to provide dose savings and protect the public health and safety in the event of an accidental release of radioactive material from a nuclear power plant. The plume exposure pathway EPZ, which is the area where predetermined, prompt protective measures are necessary, is one tool in the emergency plan.

Guidance Related to the Risk-informed Approach

TerraPower states its probabilistic risk assessment (PRA) will address all modes of operation and external hazards using the guidance in RG 1.233, Revision 0 and NEI 18-04, Revision 1. NEI 18-04 references the American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) PRA Standard, RA--S-1.4, “Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants," which the NRC staff endorsed with exceptions in RG 1.247 (for trial use), “Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor Risk-Informed Activities” (ML21235A008).[1]

Industry-developed guidance for content of applications using NEI 18-04 is provided in NEI 21-07, “Technology Inclusive Guidance for Non-Light Water Reactors – Safety Analysis Report: For Applications Utilizing the NEI 18-04 Methodology,” Revision 1 (ML22060A190). NEI 21-07 is endorsed with clarifications and additions by RG 1.253, “Guidance for a Technology-Inclusive Content of Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors,” Revision 0 (ML23269A222).

[1] This RG has been issued for trial use. The NRC staff may use a trial RG as a reference in its regulatory processes. However, the staff may withdraw or add positions from the trial use guide after the trial use period ends. Moreover, the trial use RG does not establish a staff position for the purposes of backfitting as that term is defined in 10 CFR 50.109, “Backfitting,” and as described in NRC Management Directive 8.4, “Management of Backfitting, Forward Fitting, Issue Finality, and Information Requests.” The trial RG also does not constitute forward fitting as that term is described in Management Directive 8.4.

TECHNICAL EVALUATION

TR section 1, “Introduction,” provides the purpose and scope of the TR and includes a list of abbreviations. TR section 2, “Regulatory Basis,” provides the regulatory basis for the plume exposure pathway EPZ methodology. TR section 3, “Accident Screening Methodology,” through section 7, “Summary and Conclusions on Methodology,” provide the methodology on which TerraPower requests the NRC staff’s review and approval. The NRC staff treated the information in TR sections 1 and 2 as background material supporting the methodology and takes no position on the information therein.

The TR methodology determines a plume exposure pathway EPZ based on the area within, which the dose to a member of the public is projected to exceed 10 millisievert (mSv) (1 rem) TEDE over an exposure period of 96 hours from the release of radioactive materials from the facility, considering accident likelihood and source term, timing of the release sequence, and meteorology. TR section 3.1, “Process Overview,” gives an overview of the methodology, which includes the following steps:

- Compile release sequences from the PRA for all internal and external initiators (TR sections 3.4, “Development of the Probabilistic Risk Assessment,” and 3.5, “Hazards and Initiating Events”);
- Perform screening of non-seismic release sequences based on frequency, including uncertainty (TR section 3.6, “Selection of Non-Seismic Release Sequences”);
- Perform screening of seismic release sequences with a unique set of selection criteria, including uncertainty (TR section 3.7, “Selection of Seismic Release Sequences);
- Collect meteorological data (outside the TR scope) and incorporate into the radiological consequence analysis (TR section 5.1, “Meteorological Input”);
- Perform source term and radiological consequence analysis (outside the TR scope), with the projected plume exposure pathway EPZ boundary and 96-hour event timing (TR sections 4, “Source Term Methodology,” and 5.3, “Radiological Consequence Analysis”);
- Evaluate the radiological dose consequences against the plume exposure pathway EPZ dose criteria (TR sections 3.3, “Dose-Based Criteria,” and 6.1, “Criteria for Plume Exposure Pathway Emergency Planning Zone Sizing”);
    - Determine if design changes, analysis refinements, or expansion of EPZ size are needed;
    - Address any changes by repeating the accident and consequence analyses;
- Determine the final plume exposure pathway EPZ distance based on meeting the criteria described in TR section 6.1, “Criteria for Plume Exposure Pathway Emergency Planning Zone Sizing.”

RG 1.242, appendix A, describes an acceptable approach for determining a plume exposure pathway EPZ size to meet the requirements in 10 CFR 50.33(g)(2) for SMR, non-light-water reactors (non-LWRs), or non-power production or utilization facility applicants complying with 10 CFR 50.160. This approach includes the following general steps for consequence analysis to support the determination of the plume exposure pathway EPZ:

- Identify events and radiological release scenarios for the facility;
- Develop meteorological data;
- Develop atmospheric transport, dispersion, and deposition model;
- Model potential exposures to offsite populations;

- Model potential doses to offsite populations; and
- Aggregate dose distance information.

The NRC staff reviewed TR sections 1 and 2 and determined that the TerraPower's considerations regarding the process for determining plume exposure pathway EPZ sizing methodology are consistent with the considerations in the basis for the scalable plume exposure pathway EPZ in the EP for SMRs and ONTs rule, 10 CFR 50.160. In addition, the NRC staff found that the steps of the TR methodology described in TR sections 3 through 6, as summarized in TR section 3.1, are consistent with the plume exposure pathway EPZ size analysis methodology guidance in appendix A to RG 1.242. Specifically, the TR methodology is consistent with the considerations discussed in both NUREG-0396 and RG 1.242 for determination of a plume exposure pathway EPZ that supports the objective of emergency response plans to provide dose savings for a spectrum of accidents that could produce offsite doses in excess of the Environmental Protection Agency (EPA) Protective Action Guides (PAGs)[2] for those members of the public who would most likely receive exposure as a result of a significant release.

The following sections of this SE describe the NRC staff's technical evaluation of the TR methodology steps.

1.0 Accident Screening Methodology

Section 3 of the TR provides the methodology used to determine the spectrum of accidents to include in the consequence analysis to support plume exposure pathway EPZ sizing. The NRC staff's evaluation of the steps of the accident screening methodology is described in each subsection of section 3 of the TR.

1.1 Application of risk-informed methods in event selection for EPZ sizing

TR section 3.2, "Application of Risk-Informed Methods in Event Selection," describes the use of risk information to select the events used in the plume exposure pathway EPZ sizing consequence analysis. The TR states that the risk-informed approach applies a dose-based framework with a consequence-based approach, event selections with an acceptable spectrum of consequences, and the use of a "spectrum of accidents" as the basis for the plume exposure pathway EPZ size. This approach is consistent with the guidance in RG 1.242. TR section 3.2 states that consistent with the guidance in RG 1.242, the user of the methodology will have adequate information on licensing basis events (LBEs), radiological source terms, and PRA to be applied in the plume exposure pathway EPZ sizing methodology. The TR methodology also states that event selection will be risk-informed based on release frequency using the site- and design-specific PRA. The NRC staff determined that the TR methodology to apply risk-informed methods in event selection is acceptable because it is consistent with the guidance in RG 1.242.

1.2 Dose-based criteria

TR section 3.3 provides the dose-based criteria, as applied to specific event categories. There

[2] The EPA PAGs are reference values for radiation doses that warrant preselected protective actions (e.g., evacuation or sheltering-in-place) for public protection, if the projected dose received by an individual in the absence of protective action exceeds the PAGs. The most recent version of the PAGs is given in the January 2017 EPA PAG Manual (EPA-400/R-17/001), available at https://www.epa.gov/radiation/protective-action-guides-pags.

are three dose criteria used for the methodology in the TR. Criteria A and B in section 3.3 of the TR necessitate that the projected doses from the design basis accidents (DBAs) and most radiological release sequences would not exceed PAG levels outside the plume exposure pathway EPZ, respectively. The NRC staff notes that the TR use of the EPA PAGs as a basis for Criteria A and B is consistent with the goals for emergency planning as described in NUREG-0396, the plume exposure pathway EPZ sizing methodology guidance in RG 1.242, and the dose criterion for the EPZ size in 10 CFR 50.33(g)(2)(i). Therefore, the NRC staff determined that the dose-based Criteria A and B and their bases are acceptable.

Criterion C necessitates that immediate life-threatening doses from the worst-case radiological release sequences would generally not occur outside the plume exposure pathway EPZ. The EPZ size criteria in 10 CFR 50.33(g)(2)(i) are based on determination of the area where the lower end of the EPA PAG levels (i.e., 10 mSv (1 rem) TEDE over 96 hours) would be exceeded from release of radioactive materials from the facility considering accident likelihood and source term, timing of the accident sequence, and meteorology. Although the regulatory requirement in 10 CFR 50.33(g)(2)(i) does not specifically provide dose metrics that vary with likelihood of the release, the probabilistic dose aggregation guidance in RG 1.242, appendix A, states that the likelihood of exceeding the plume exposure pathway EPZ dose criterion should be consistent with the evaluation in appendix I to NUREG-0396. TR Criterion C gives an immediately life-threatening dose metric for very low probability radiological release sequences. TR Criterion C is similar to the criterion for the evaluation of the worst core melt sequences in NUREG-0396, where it was determined that there was a low likelihood that immediately life-threatening doses would be projected outside of the 10-mile plume exposure pathway EPZ for the evaluated set of large light water reactor severe accidents with core melt and containment bypass or failure. As stated in TR section 6.1.3, “Worst Radiological Release Sequences,” Criterion C is evaluated using a 24-hour exposure 200 rem red bone marrow acute effective dose. The NRC staff determined that this dose metric is comparable to the dose metric of 200 rem whole body acute dose used in the NUREG-0396 analyses for the worst-case core melt sequences.

The release frequencies for events selected to be compared to TR Criterion C are important when the intent of the TR methodology criterion is to be consistent with the NUREG-0396 evaluation, which considered the event frequencies as well as scenario characteristics for the worst core melt sequences.

TR sections 3.6 and 3.7 describe the risk-informed selection of release sequences to compare to each of the criteria, as supported by information in TR sections 3.4 and 3.5. The NRC staff’s evaluation of the TR event selection methodology is described in the following SE subsections 1.3 through 1.6. SE subsection 4.1 describes the NRC staff’s evaluation of the TR section 6.1 description of the TR methodology evaluation of the dose results against the dose-based criteria.

1.3 Development of PRA

RG 1.242, appendix A, section A-3.1 provides guidance on the selection of events to use in the consequence analysis to determine the facility-specific plume exposure pathway EPZ size. The guidance states that the applicant should consider the LBEs relevant to the facility described in the facility safety analysis report as candidates for development of potential radiological releases. As discussed in TR section 3.4, the technology-inclusive, risk-informed, and performance-based methodology in NEI 18-04, as endorsed by RG 1.233, is used to determine LBEs. While TerraPower chose not to explicitly use the LBEs in its methodology, the PRA

developed for implementation of NEI 18-04 is used. RG 1.242, appendix A, acknowledges that the development of the licensing basis in conformance with RG 1.233 is an option for non-LWRs.

The development and use of PRA is a fundamental part of the NEI 18-04 methodology. TR section 3.4 states that the PRA will be developed using the guidance in the non-LWR PRA standard (ASME/ANS RA-S-1.4) and will address the full spectrum of internal events and external hazards, as well as all operating modes. TerraPower also stated that the PRA will be peer reviewed and meet the non-LWR PRA standard before the submittal of the final plume exposure pathway EPZ sizing analysis for a facility application. RG 1.233 states that the methodology in NEI 18-04 includes an expanded role for PRA and that the NRC staff's review of the PRA prepared by a reactor designer could be facilitated by the designer's use of the NRC staff-endorsed consensus codes and standards. RG 1.247 (for trial use) describes the acceptability of PRA for purposes such as supporting the NEI 18-04 methodology.

As discussed in TR section 3.4, the PRA is used to select the spectrum of events used in the plume exposure pathway EPZ sizing methodology. TerraPower states that event sequences for all internal and external events, and for all operating modes will be considered. The TR methodology uses PRA information directly instead of starting with the LBEs determined through the NEI 18-04 process. The TR methodology includes a review of the assumptions and sources of uncertainty in the PRA to identify and address any effect on the plume exposure pathway EPZ sizing methodology. TR sections 3.5 through 3.7 describe the selection of events for the plume exposure pathway EPZ sizing methodology.

1.4 Hazards and initiating events

TR section 3.5 describes the methodology for evaluating a broad spectrum of events including hazard groups from the non-LWR PRA standard ASME/ANS RA-S-1.4. Events that are screened out will be identified and documented with justification. The TR methodology will include accident phenomena as analyzed in the PRA which are found to be applicable to the Natrium reactor design. As stated in TR section 3.5.3, "Other Risk Events" the methodology will also evaluate other risks which are design- or site-specific that may lead to potential offsite radionuclide releases that may impact plume exposure pathway EPZ sizing. The NRC staff determined that the TR identification of hazards and initiating events is acceptable because the scope of potential events is consistent with the guidance in RG 1.242.

Although not addressed by the PRA standard ASME/ANS RA-S-1.4, the TR methodology considers security events for completeness. TR section 3.5.2 discusses how security events and accidents resulting from security events will be addressed. Specifically, the TR methodology states that a qualitative or quantitative assessment of security events will be documented in the plume exposure pathway EPZ size calculation to ensure that security events are addressed, and the associated risks are captured within the calculation. The NRC staff determined that the TR treatment of security events in the calculation is aligned with and provides additional information compared to the guidance in RG 1.242 regarding event selection and is therefore acceptable.

As discussed in TR section 3.5.4, "Event Groupings," the PRA will support the categorization and evaluation of events to be used in the plume exposure pathway EPZ sizing analysis. The plume exposure pathway EPZ sizing events will be identified by using the PRA event sequences, event sequence families, and groupings, as included in the PRA documentation. The NRC staff determined that the use of PRA to support categorization and evaluation of

plume exposure pathway EPZ events is acceptable because it is consistent with the guidance in RG 1.242 and RG 1.247.

1.5 Selection of non-seismic release sequences

TR section 3.6.1, “Criterion,” discusses the screening criteria for selection of non-seismic release sequences. The DBAs determined in the LBEs will be included. Non-seismic release sequences with mean frequencies greater than or equal to $1x10^{-7}$ per reactor-year and those sequences that contribute 1% or more to the overall release frequency will be included. Individual events and groups with mean frequency sums greater than $1x10^{-8}$ per reactor-year will be considered for cliff-edge effects. The NRC staff determined that this non-seismic release sequence screening approach is acceptable because it would result in a spectrum of events consistent with that evaluated in NUREG-0396 and, with the difference analyzed below, discussed in RG 1.242.

Cliff-edge effects evaluation involves identifying and addressing scenarios where small changes in input parameters—such as initiating event frequencies; structures, systems, components (SSCs) failure probabilities; or assumptions—can lead to disproportionately large changes in risk outcomes. The staff’s review identified a difference between TerraPower’s proposed methodology to be used to determine the PEP EPZ sizing for proposed Natrium reactor design and item B-3 in Appendix B of RG 1.242 regarding the cliff-edge effects evaluation. The proposed methodology specifies that individual events and groups with combined frequencies between 1×10^{-7} per reactor-year and 1×10^{-8} per reactor-year will be considered for cliff-edge effects and that individual events and groups with combined frequencies 1×10^{-8} per reactor-year or less would be discarded. RG 1.242, however, retains event sequences with frequencies below the cutoff threshold to confirm the absence of cliff-edge effects.

Unlike RG 1.242, which does not reference the non-light water reactor (NLWR) PRA standard or impose conformance to it, the TerraPower proposed methodology specifies that the PRAs will follow the guidance in the NLWR PRA standard, undergo peer review, and meet all NLWR PRA standard requirements. Furthermore, the NRC staff imposed Limitations and Conditions in this SE to ensure that PRAs supporting the proposed methodology address all applicable hazards, all modes, all sources of radioactive material, and maintain technical acceptability.

The NLWR PRA standard includes specific requirements for addressing cliff-edge effects, considering various approaches to minimize these associated risks. By conforming to the NLWR PRA standard:

- All applicable initiating events, including equipment failures, human errors, and external hazards, are properly considered;
- Modeling captures low-frequency events, concurrent initiating events, secondary hazards, and combinations of hazards, ensuring comprehensive representation of possible severe outcomes;
- Conservative estimates for event frequencies, failure probabilities, success criteria, etc., account for worst-case scenarios;
- Intersystem and intrasystem common-cause failures and intersystem and intrasystem dependencies are modeled to ensure that redundant systems are thoroughly analyzed and not simultaneously significantly affected by a same event;
- Uncertainty and sensitivity analyses comprehensively identify critical parameters driving risk and focus efforts on reducing risk; and

- The oversimplification of event sequences that might obscure severe consequences would be avoided.

The proposed Natrium power plant design includes inherent redundancy and diversity, supported by defense-in-depth strategies. These design features provide multiple independent protective layers and sufficient safety margins to mitigate cliff-edge effects and address uncertainties effectively. Moreover, importance measures, such as risk achievement worth, provide insights into SSC performance to minimize the risks associated with cliff-edge effects. In addition, peer review of PRA models will further consider expert evaluation to confirm that cliff-edge effects are adequately addressed.

Based on the above, regardless of the $1x10^{-8}$ per reactor-year cutoff frequency cited in the TR methodology, an applicant referencing this TR will justify that cliff-edge effects have been thoroughly evaluated and identify and address the risks associated with low-frequency events. Therefore, considering the factors mentioned above and conformance to NLWR PRA standard requirements and RG 1.247, the NRC staff determined that cliff-edge effects will be appropriately identified and addressed when implementing the proposed PEP EPZ sizing methodology.

TR section 3.6.2, “Parameter Uncertainty,” describes the treatment of uncertainties in the screening of non-seismic release sequences. The NRC staff determined that the uncertainty treatment is acceptable because it is consistent with guidance in NUREG-1855, Revision 1, “Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decisionmaking” (ML17062A466), which is a reference in RG 1.242.

1.6 Selection of seismic release sequences

TR section 3.7 describes the criterion for seismic event selection using insights from a site-specific scoping level seismic PRA (SPRA) to establish a limiting peak ground acceleration (PGA) for the site for use in the plume exposure pathway EPZ sizing methodology. The TR states that the limiting PGA would be aligned to achieve at least two times the ground motion response spectrum (GMRS) for the site with the intent to limit the range of seismic hazard under consideration within the credible range of ground motions. However, the TR also states an upper bound PGA of 1.0 gravitational acceleration (g) will be used to acknowledge the limitations of the SPRA and uncertainties associated with the availability of local and state emergency response infrastructure at large ground motions.

The limiting PGA will be used to establish the bounding seismic event for the plume exposure pathway EPZ for a construction permit application. The TR states that this bounding seismic event is expected to capture the important phenomena that will challenge the required safety functions and radiological barriers from a seismic event. The limiting PGA will then be used as the event screening threshold for the selection of plume exposure pathway EPZ events for the seismic plume exposure pathway EPZ sizing calculation for an operating license application. The TR further states that the limiting seismic scenario identified at the construction permit phase is expected to capture the important phenomena that will challenge the required safety functions and radiological barriers after a seismic event. TR section 3.7.2, “Parameter Uncertainty,” describes how the bounding seismic scenario accounts for uncertainty and evaluates for cliff-edge effects by using insights from the SPRA.

For the early stages of design (i.e., construction permit stage), the NRC staff determined that

the use of the scoping level SPRA is acceptable if it is of sufficient technical adequacy to support its role in the plume exposure pathway EPZ sizing analysis. However, the NRC staff notes that the seismic scenario selection methodology described in section 3.7 of the TR could potentially result in a scenario that may not be representative of the potential accident consequences that should be included in determining the Plume Exposure Pathway EPZ for the Natrium reactor design at a specific site. Specifically, in the case of a site for which two times the GMRS would result in a PGA that exceeds 1.0 g, it is not clear that basing the selection of the seismic release scenario on an upper bound PGA of 1.0 g would be encompassing of most seismic release sequences for the facility without further information on the potential scenarios. Therefore, the NRC staff imposes Limitation and Condition 5, below, on the use of this TR for applications that utilize the upper bound PGA of 1.0 g to determine the seismic scenario. Subject to this condition that requires additional site-specific justification, the NRC staff concludes that the TR determination of a bounding seismic event is based on a review of the full spectrum of seismic events, as informed by frequency considerations and impact to the facility. Additionally, with the inclusion of this condition, the NRC staff determined that the selection of seismic release sequences is consistent with guidance in RG 1.242 and is acceptable because the bounding seismic event used is bounding for most release sequences and accounts for the dose consequences of seismic events as well as uncertainty.

1.7 Release timing

TR section 3.8, “Release Timing,” states that the timing of release of radionuclides is an input to the TR methodology. Release timing will be determined by the source term methodology and is therefore out of scope of the TR methodology. Radionuclide release timing information will be used if necessary to identify the events that require prompt protective measures. The staff determined that this is consistent with the guidance in RG 1.242 and is acceptable.

2.0 Source Term Methodology

TR section 4, “Source Term Methodology,” states that methodology to develop mechanistic source terms associated with the release scenarios selected for plume exposure pathway EPZ sizing is consistent with the overall Natrium reactor assessment and projections. The NRC staff understands that this is referring to the development of mechanistic source terms for application safety analysis report analyses and the Natrium PRA. The source terms for the release scenarios are treated as input to the TR methodology. The TR states that the development of source terms is addressed in a separate TR (NAT-9392, “Radiological Source Term Methodology Report” (ML24261B944)), and therefore is out of scope of this TR. The NRC staff determined that referencing accident radiological source terms from the safety analysis for the facility is acceptable because it is consistent with guidance in RG 1.242, appendix A, item A-3.2. The NRC staff will review the development of source terms as part of its review of a related license application and the implementation of the related TR on radiological source term methodology.

3.0 Radiological Consequence Considerations

3.1 Radiological consequence analysis

TR section 5, “Radiological Consequence Considerations,” describes the radiological consequence analysis for the methodology. TR sections 5.1 through 5.3 describe the

considerations for analyzing the radiological consequences of the selected events. The TerraPower radiological consequence analysis methodology is described in NAT-9391, "Radiological Release Consequences Methodology Topical Report" (ML24208A181), which at this time is under NRC staff review. The EPZ sizing methodology TR briefly discusses meteorological and population data, as well as the use of the MELCOR Accident Consequence Code System (MACCS). The EPZ sizing methodology TR also identifies that the initial plume exposure pathway EPZ sizing calculation will use 12 consecutive months of representative data, while the final plume exposure pathway EPZ sizing analysis will use a full two-year set collected from the site-specific meteorological data. The NRC staff determined that this approach is acceptable because it is consistent with the guidance in RG 1.242 and the discussion of meteorology and atmospheric dispersion in the interim staff guidance for the Advanced Reactor Content of Application Project DANU-ISG-2022-02, chapter 2, "Site Information" (ML23277A140).

The NRC staff evaluated the subject TR discussion with respect the use of the output of the radiological consequences methodology as input to the plume exposure pathway EPZ sizing analysis methodology. The TR states that the consequence analysis methodology will be the same as the LBE consequence analysis methodology with the exception that the doses will be calculated for a 96-hour or 24-hour exposure period instead of the 30-day dose needed for the LBE methodology. The NRC staff determined that the calculation of 96-hour dose is acceptable because it is consistent with the requirements in 10 CFR 50.33(g)(2)(i) and the guidance in RG 1.242.

The TR methodology also evaluates acute whole-body dose for a comparison of the worst-case radiological release sequences to a separate criterion related to immediate life-threatening doses discussed in TR section 6.1.3. The NRC staff's evaluation of this criterion is given below in SE section 4.1. The NRC staff determined that the calculation of a 24-hour exposure for the acute dose is acceptable because it is consistent with the time period used for a similar substantial reduction in early deterministic health effect criterion in NUREG-0396. TR section 5.3 states that the consequence analysis will not model protective actions such that there is no credit for evacuations, relocations, or sheltering of the public. The NRC staff determined that that no modeling of protective actions is acceptable because it is consistent with the guidance in RG 1.242 for plume exposure pathway EPZ sizing consequence analysis.

3.2 Dose estimation for pathway contributors

TR section 5.4, "Dose Estimation for Pathway Contributors," describes the dose pathways modeled in the consequence analysis, and states that the evaluation against the three TR criteria is done in an iterative process to determine the appropriate distance for the boundary of the plume exposure pathway EPZ for a specific facility license application. If any of the dose-based criteria are exceeded at a chosen EPZ boundary distance (nominally the site boundary) during the design phase, then an applicant using this TR would perform subsequent analyses that either change the EPZ boundary distance or make changes to the reactor design to reduce potential offsite consequences or, for the events screened into the worst-case radiological release sequences, change the release frequencies. Exposure pathways include cloud shine, inhalation, resuspension, and ground shine, which is consistent with the guidance in RG 1.242. The dose results calculated are TEDE to the individual for Criteria A and B, and red bone marrow effective acute dose to the individual for Criterion C. TR section 5.4 provides a justification for use of red bone marrow effective acute dose in lieu of whole-body acute dose. The NRC staff determined that that TEDE is consistent with the 10 CFR 50.33(g) requirements and RG 1.242, while the red bone marrow effective acute dose is consistent with the evaluation

in NUREG-0396 for very severe accidents.

4.0 Probabilistic Dose Aggregation

Section 6, “Probabilistic Dose Aggregation,” of the TR describes the methodology for aggregating doses from different source terms with consideration of the associated frequencies, to provide confidence that the appropriate plume exposure pathway EPZ size has been determined and that risk to the general public is minimized. The NRC staff’s evaluation of the probabilistic dose aggregation including comparison to the dose-related criteria, determination of the necessity of predetermined prompt protective measures and treatment of uncertainty is described below.

4.1 Dose-related criteria for plume exposure pathway EPZ sizing

TR section 6.1 describes the evaluation of the three dose-related criteria in the TR methodology and states that the plume exposure pathway EPZ will be established at the furthest distance at which all three criteria will be met. In Criterion A for each DBA in the licensing basis, a mechanistic source term will be developed using the TerraPower radiological source term methodology and the consequences evaluated using the TerraPower radiological release consequence analysis methodology (NAT-9392 and NAT-9391, respectively). The mean 96-hour TEDE will be compared to a dose level of 10 mSv (1 rem) TEDE, which is the lower end of the EPA PAG. The 95^{th} percentile 96-hour TEDE will be compared to a dose level of 50 mSv (5 rem), which is the upper end of the EPA PAG. Criterion B for most radiological release sequences is handled in the same way as DBAs, with consideration of events screened into the plume exposure pathway EPZ sizing analysis with mean release frequencies greater than $1x10^{-6}$. The NRC staff determined that these groupings of events and the associated dose-related criteria are acceptable since they are similar to those evaluated in NUREG-0396 and discussed in RG 1.242.

Events screened into the plume exposure pathway EPZ sizing analysis with mean release frequencies below $1x10^{-6}$ but greater than $1x10^{-7}$ are compared to Criterion C for the worst-case radiological release sequences. The consequences of these events will be compared to a dose metric of 200 rem red marrow acute effective dose for a 24-hr exposure period. Additionally, these events will be analyzed to ensure that the dose drops rapidly beyond the plume exposure pathway EPZ boundary by generating a dose-distance chart mapping the dose reduction as one moves away from the EPZ. The NRC staff notes that the lower end frequency used to determine the worst-case radiological release scenarios is lower than that used to evaluate beyond design basis events in the NEI 18-04 process. This difference, along with the cliff-edge effect evaluations for events with mean frequencies as low as $1x10^{-8}$, as described in TR section 6.3, “Uncertainty and Sensitivity Analysis Methodology,” will ensure that very low probability events with potentially high consequences will not be inappropriately scoped out of the plume exposure pathway EPZ sizing analysis. The NRC staff determined that this evaluation of worst-case radiological release sequences and the associated dose-related criteria is acceptable because the evaluation is similar to those worst core melt accidents evaluated in NUREG-0396 and referred to in RG 1.242, appendix A, on probabilistic dose aggregation.

4.2 Necessity of predetermined prompt protective measures

The plume exposure pathway EPZ sizing requirements in 10 CFR 50.33(g)(2)(i)(B) state that the plume exposure pathway EPZ is that area within which predetermined, prompt protective measures are necessary. TR section 6.2, “Necessity of Predetermined Prompt Protective

Measures," describes the use of radiological release timing to identify the necessity of prompt protective measures for the events included in the plume exposure pathway EPZ sizing analysis. The timing of each event will be assessed individually and if any event is identified to need prompt protective measures and it exceeds the relevant dose-related criterion, the iterative evaluation process will be followed as described in TR section 6.2 until the appropriate plume exposure pathway EPZ is established. Identified protective measures will inform the emergency plan and procedures. The NRC staff determined that the use of radiological release timing to determine the necessity of prompt protective measures is acceptable because it is consistent with the guidance in RG 1.242, appendix A.

LIMITATIONS AND CONDITIONS

The NRC staff imposes the following limitations and conditions with regard to the use and approval of the subject TR:

1. The PRAs used to implement the TR methodology will be design- and site-specific and developed for all applicable hazards, all modes, and all sources of radioactive material, using the guidance in RG 1.247 "Acceptability of Probabilistic Risk Assessment Results for Non-Light-Water Reactor Risk-Informed Activities" and appendix A to RG 1.253 "Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors" (ML23269A222). Prior to the initial fuel loading, any exceptions to meeting capability categories referred to in RG 1.247 should be justified and documented.
2. An applicant that references this TR must justify the technical acceptability of the PRAs performed for the selected hazards and modes (e.g., site-specific scoping level seismic PRA). Prior to the initial fuel loading, PRAs supporting this methodology must include all applicable hazards and modes.
3. An applicant that references this TR must provide discussions of (1) how PRA key assumptions and key sources of uncertainty for each analyzed hazard, mode, and radioactive source were identified; (2) how the key assumptions and key sources of uncertainty identified as having the potential to significantly impact the PRA results have been characterized in a manner consistent with the current state of knowledge; and 3) how the impact of each identified key assumption and source of uncertainty was assessed and dispositioned.
4. An applicant that references this TR must justify that the scoping level seismic PRA is of sufficient technical acceptability. This means that the model will be design- and site-specific and developed based on acceptable methods and data. The engineering analyses, assumptions, and approximations used in developing the scoping level seismic PRA should be appropriate and should demonstrate the robustness of the conclusions with respect to the uncertainties in the assessment. Prior to the initial fuel loading, an applicant that references this TR must reassess the EPZ size using a seismic PRA that meets the requirements of non-LWR PRA standard, as endorsed in RG 1.247, to the extent necessary to support plume exposure pathway EPZ sizing calculation.
5. An applicant that references this TR will provide site-specific justification for the use of the upper bound PGA of 1.0 g when exercising the methodology in TR section 3.7, "Selection of Seismic Release Sequences," to choose the seismic scenario for the EPZ sizing analysis.
6. A periodic evaluation of the plume exposure pathway EPZ sizing analysis must be performed following an update or upgrade to the user's PRAs based on a review of changes to the plant structures, systems, and components, operational practices, and applicable plant and industry operational experience. Any changes to the emergency preparedness plan as a result of the evaluation should be conducted under 10 CFR 50.54(q).

CONCLUSION

The NRC staff has completed its review of TR number NAT-3056, “TerraPower, LLC (TerraPower) Natrium™ Topical Report: Plume Exposure Pathway Emergency Planning Zone Sizing Methodology.” Based on its evaluation the NRC staff determined that NAT-3056, Revision 3, subject to the limitations and conditions discussed above, provides an approach acceptable to the NRC staff to develop analyses to aid in the determination of a site- and design-specific plume exposure pathway EPZ for the Natrium reactor. Accordingly, the NRC staff concludes that the subject TerraPower TR can be used in establishment of the plume exposure pathway EPZ size support emergency planning and preparedness in compliance with the regulatory requirements in 10 CFR 50.33(g) and 10 CFR 50.47(c)(2), as applicable, for prospective TerraPower Natrium reactor construction permit or operating license applications under 10 CFR Part 50.

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SUBJECT: 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) DATED: November 20, 2024

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