July 25, 2025

TP-LIC-LET-0442
Docket Number 50-613

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
ATTN: Document Control Desk

Subject: Submittal of Approved TerraPower, LLC Radiological Release Consequences Methodology Topical Report

References: 1. U.S. Nuclear Regulatory Commission, TerraPower, LLC – Final Safety Evaluation of Topical Report NAT-9391, Radiological Consequences Methodology, Revision 0 (ML25106A264)

The U.S. Nuclear Regulatory Commission (NRC) provided the final safety evaluation for the TerraPower, LLC (TerraPower) Radiological Release Consequences Topical Report in Reference 1. The topical report provides an overview and description of the model developed to evaluate radiological release consequences for the Natrium®[1] Plant.

Enclosures 2 and 3 of this letter provide the accepted version of the topical report with additional content incorporated per NRC staff request, designated NAT-9391-A.

The report contains proprietary information and as such, it is requested that Enclosure 3 be withheld from public disclosure in accordance with 10 CFR 2.390, "Public inspections, exemptions, requests for withholding." An affidavit certifying the basis for the request to withhold Enclosure 3 from public disclosure is included as Enclosure 1. Proprietary materials have been redacted from the report provided in Enclosure 2; redacted information is identified using [[ ]]$^{(a)(4)}$.

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[1] Natrium is a TerraPower and GE-Hitachi Technology.

This letter and the associated enclosures make no new or revised regulatory commitments.

If you have any questions regarding this submittal, please contact Ian Gifford at igifford@terrapower.com.

Sincerely,

George Wilson

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC

Enclosures:
1. TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))
2. TerraPower, LLC Topical Report NAT-9391-A, Revision 0, Radiological Release Consequences Methodology – Non-Proprietary (Public)
3. TerraPower, LLC Topical Report NAT-9391-A, Revision 0, Radiological Release Consequences Methodology – Proprietary (Non-Public)

cc: Mallecia Sutton, NRC
Josh Borromeo, NRC
Nathan Howard, DOE

ENCLOSURE 1

TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure (10 CFR 2.390(a)(4))

Enclosure 1
TerraPower, LLC Affidavit and Request for Withholding from Public Disclosure
(10 CFR 2.390(a)(4))

I, George Wilson, hereby state:

1. I am the Senior Vice President, Regulatory Affairs and I have been authorized by TerraPower, LLC (TerraPower) to review information sought to be withheld from public disclosure in connection with the development, testing, licensing, and deployment of the Natrium® reactor and its associated fuel, structures, systems, and components, and to apply for its withholding from public disclosure on behalf of TerraPower.
2. The information sought to be withheld, in its entirety, is contained in Enclosure 3, which accompanies this Affidavit.
3. I am making this request for withholding, and executing this Affidavit as required by 10 CFR 2.390(b)(1).
4. I have personal knowledge of the criteria and procedures utilized by TerraPower in designating information as a trade secret, privileged, or as confidential commercial or financial information that would be protected from public disclosure under 10 CFR 2.390(a)(4).
5. The information contained in Enclosure 3 accompanying this Affidavit contains non-public details of the TerraPower regulatory and developmental strategies intended to support NRC staff review.
6. Pursuant to 10 CFR 2.390(b)(4), the following is furnished for consideration by the Commission in determining whether the information in Enclosure 3 should be withheld:

    a. The information has been held in confidence by TerraPower.
    b. The information is of a type customarily held in confidence by TerraPower and not customarily disclosed to the public. TerraPower has a rational basis for determining the types of information that it customarily holds in confidence and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application and substance of that system constitute TerraPower policy and provide the rational basis required.
    c. The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR 2.390, it is received in confidence by the Commission.
    d. This information is not available in public sources.
    e. TerraPower asserts that public disclosure of this non-public information is likely to cause substantial harm to the competitive position of TerraPower, because it would enhance the ability of competitors to provide similar products and services by reducing their expenditure of resources using similar project methods, equipment, testing approach, contractors, or licensing approaches.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on: July 25, 2025

George Wilson

George Wilson
Senior Vice President, Regulatory Affairs
TerraPower, LLC

ENCLOSURE 2

TerraPower, LLC Topical Report
“Radiological Release Consequences Methodology,”
NAT-9391-A, Revision 0

Non-Proprietary (Public)

TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

A TerraPower & GE-Hitachi Technology

Radiological Release Consequences Methodology

NAT-9391-A

Revision 0

July 2, 2025

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

May 13, 2025

George Wilson
Vice President, Regulatory Affairs
TerraPower, LLC
15800 Northup Way
Bellevue, WA 98008

SUBJECT: TERRAPOWER, LLC – FINAL SAFETY EVALUATION FOR NATRIUM TOPICAL REPORT NAT-9391, “RADIOLOGICAL RELEASE CONSEQUENCES METHODOLOGY TOPICAL REPORT,” REVISION 0 (EPID L-2023-TOP-0055)

Dear George Wilson:

By letter dated November 6, 2023, TerraPower, LLC (TerraPower) submitted Topical Report (TR), TP-LIC-RPT-0005, “Radiological Release Consequences Methodology Topical Report,” (Agencywide Documents Access and Management System (ADAMS) Accession No. ML23311A139) for the U.S. Nuclear Regulatory Commission (NRC) staff’s review which contains an overview and description of the models developed to evaluate the consequences of radiological release source terms for the proposed Natrium sodium fast reactor (SFR) nuclear power plant design. On December 18, 2023, the NRC staff found that the material presented in the TR provides technical information in sufficient detail for the NRC staff to conduct a detailed technical review (ML23333A070).

On April 24, 2024, the NRC staff transmitted an audit plan to TerraPower (ML24103A224). From May 7, 2024, through June 28, 2024, 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. The NRC staff issued the audit summary on January 23, 2025 (ML25024A041). On July 26, 2024, TerraPower submitted a revision to TP-LIC-RPT-0005, renumbered as NAT-9391, Revision 0 (ML24208A181) that addressed items discussed during the NRC staff audit and other minor editorial corrections.

The enclosed final SE is being provided to TerraPower, because the NRC staff has found NAT-9391, Revision 0, acceptable for referencing in licensing actions to the extent specified and under the limitations and conditions delineated in the SE. The final SE defines the basis for the NRC staff’s acceptance of the TR.

The NRC staff requests that TerraPower submit to NRC staff an approved version of this TR within three months of receipt of this letter. The approved version should incorporate this letter and the enclosed SE after the title page. The approved version should include a “-A” (designating approved) following the TR identification symbol.

If you have any questions, please contact Roel Brusselmans at (301) 415-0829 or via email at Roel.Brusselmans@nrc.gov.

Sincerely,

/RA/

Joshua Borromeo, Chief
Advanced Reactor Licensing Branch 1
Division of Advanced Reactors and Non-Power
Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No.: 99902100

Enclosure:
As stated

cc: TerraPower Natrium via GovDelivery

SUBJECT: TERRAPOWER, LLC – FINAL SAFETY EVALUATION FOR NATRIUM TOPICAL REPORT NAT-9391, “RADIOLOGICAL RELEASE CONSEQUENSES METHODOLOGY TOPICAL REPORT,” REVISION 0 (EPID L-2023-TOP-0055) DATED: MAY 13, 2025

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WASHINGTON, D.C. 20555-0001

TERRAPOWER, LLC. – FINAL SAFETY EVALUATION OF NAT-9391, "RADIOLOGICAL RELEASE CONSEQUENCES METHODOLOGY TOPICAL REPORT," REVISION 0 (EPID NO. L-2023-TOP-0055)

SPONSOR AND SUBMITTAL INFORMATION

Sponsor: TerraPower, LLC

Sponsor Address: 15800 Northup Way, Bellevue, WA 98008

Project No.: 99902100

Submittal Date: November 6, 2023

Submittal and Supplements Agencywide Documents Access and Management System (ADAMS) Accession Nos.: ML23311A139, ML24208A180

Brief Description of the Topical Report: By letter dated November 6, 2023, TerraPower, LLC (TerraPower) submitted Topical Report (TR), TP-LIC-RPT-0005, "Radiological Release Consequences Methodology Topical Report," (ML23311A139) for the U.S. Nuclear Regulatory Commission (NRC) staff's review. A separate TR, TP-LIC-LET-0093, "Radiological Source Term Methodology Report" (ML23223A235) documents the determination of the relevant radiological source terms for the proposed Natrium sodium fast reactor (SFR) nuclear power plant design.[1] The TR under review in this safety evaluation provides those three evaluation models (EMs), which can be used to determine the consequences of radiological release source terms for the proposed Natrium SFR nuclear power plant design.[2] On December 18, 2023, the NRC staff found that the material presented in the TR provides technical information in sufficient detail to enable the NRC staff to conduct a detailed technical review (ML23333A070). From May 7, 2024, through June 28, 2024, 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 (ML24103A224). On July 26, 2024, TerraPower submitted a revision to TP-LIC-RPT-0005, renumbered as NAT-9391, Revision 0 (ML24208A181) that addressed items discussed during the NRC staff audit and other minor editorial corrections. The audit report summarizing the NRC staff's observations was issued on January 23, 2025 (ML25024A041).

For background, TerraPower's overall licensing approach for applications related to the proposed 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

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[1] The referenced radiological source term methodology TR is under NRC review concurrently and has been revised and renumbered as NAT-9392, Revision 0, (ML24261B944).
[2] For clarity purposes, when this safety evaluation refers to the TR, it is referring to the TR under NRC review in this safety evaluation.

Enclosure

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. The EMs described in the TR are consistent with estimating the radiological consequences of accidental radiological releases to the environment to comply with relevant regulatory requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," including, in part, through the use of the LMP methodology.

REGULATORY EVALUATION

This TR was submitted in support of TerraPower's current and planned license applications under 10 CFR Part 50. Specific regulations relevant to TerraPower's radiological release consequences methodology include:

- The requirements in 10 CFR 50.34(a) describe the minimum information required for the preliminary safety analysis report (PSAR) supporting a construction permit (CP) application, including the following:
  - Title 10 CFR 50.34(a)(1)(ii)(D) requires that the PSAR provide a description and safety assessment of the site and a safety assessment of the facility. In doing this special attention must be directed to plant design features intended to mitigate the radiological consequences of accidents. This evaluation must determine that

    > "(1) An individual located at any point on the boundary of the exclusion area for any 2 hour period following the onset of the postulated fission product release, would not receive a radiation dose in excess of 25 rem[ ] total effective dose equivalent (TEDE)
    >
    > "(2) An individual located at any point on the outer boundary of the low population zone [(LPZ)], who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a radiation dose in excess of 25 rem [TEDE]."
  - Title 10 CFR 50.34(a)(3)(i) requires that the PSAR include the principal design criteria (PDC) for the facility. Natrium-specific PDC are provided in approved TerraPower TR NATD-LIC-RPRT-0002-A, "Principal Design Criteria for the Natrium Advanced Reactor," Revision 1 (ML24283A066). One EM in the radiological release consequences methodology is used to determine control room (CR) dose consequences to show that the design meets the radiological habitability requirements in Natrium PDC 19, "Control room." In this SE, the NRC staff is only evaluating this methodology, not PDC 19 and the corresponding CR dose criterion.
  - Title 10 CFR 50.34(a)(4) requires, in part, that "[a] preliminary analysis and evaluation of the design and performance of structures, systems, and components [(SSCs)] of the facility with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of [SSCs]

provided for the prevention of accidents and the mitigation of the consequences of accidents."

- The requirements in 10 CFR 50.33(g)(2), requires, in part, that "[s]mall modular reactor, non-light-water reactor, or non-power production or utilization facility applicants complying with [10 CFR] 50.160 who apply for a [CP] or an operating license under [10 CFR 50] . . . must submit as part of the application the analysis used to determine whether the criteria in [10 CFR] 50.33(g)(2)(i)(A) and (B) are met and, if they are met, the size of the plume exposure pathway [(PEP) emergency planning zone (EPZ)]."

Specific guidance documents relevant to TerraPower's radiological release consequences methodology include:

- RG 1.233, Revision 0.
- RG 1.247 (For Trial Use), "Acceptability of Probabilistic Risk Assessment Results for Non-Light Water Reactor Risk-Informed Activities" (ML21235A008).
    - NEI 18-04 references the American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) probabilistic risk assessment (PRA) standard, RA-S-1.4-2021, "Probabilistic Risk Assessment Standard for Advanced Non-Ligh Water Reactor Nuclear Power Plants," which is endorsed with exceptions in RG 1.247. The NRC staff's review was informed, in part, by guidance on the elements of a radiological consequence analysis contained in RG 1.247 and ASME/ANS RA-S-1.4-2021.
- RG 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," Revision 1 (ML23082A305). Specifically, section 4, "Dose Calculation Methodology" and section 5.3, "Atmospheric Dispersion Modeling and Meteorology Assumptions."
- RG 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Revision 1 (ML003740205).
- RG 1.242, "Performance-Based Emergency Preparedness for Small Modular Reactors, Non-Light-Water Reactors, and Non-Power Production or Utilization Facilities," Revision 0 (ML23226A036).
- RG 1.249, "Use of ARCON Methodology for Calculation of Accident-Related Offsite Atmospheric Dispersion Factors," Revision 0 (ML22024A241).
- RG 1.253, "Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content for Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," Revision 0 (ML23269A222).
    - Endorses NEI 21-07, Revision 1, "Technology Inclusive Guidance for Non-Light Water Reactors, Safety Analysis Report Content for Applicants Using the NEI 18-04 Methodology" (ML22060A190).

TECHNICAL EVALUATION

1.0 INTRODUCTION

TR section 1, "Executive Summary," TR section 2, "Introduction," and TR section 7, "References," provide a summary of the TR methodology which includes three EMs and an appendix describing modifications to the licensing basis event (LBE) EM for use in PEP EPZ sizing analysis, the TR objective and scope, and TR references, respectively. The remainder of the TR provides the radiological release consequences EMs for NRC staff's review and approval: section 3, “Licensing Basis Event Evaluation Model;” section 4, “Design Basis Accident Evaluation Model;” section 5, “Control Room Habitability Evaluation Model;” section 6, “Conclusions on Evaluation Models;” and the appendix, “Adaptation of Licensing Basis Event Evaluation Model to Emergency Planning Zone Sizing.” For each EM described in TR sections 3 through 5, the section includes a subsection on the objective and scope of the EM, the relevant regulatory requirements and guidance, EM inputs, the computational model, and other topics pertinent to the EM. The appendix describes adjustments to the EM described in TR section 3 to provide the dose results for the PEP EPZ sizing analysis methodology as described in a separate TerraPower TR NAT-3056, “Plume Exposure Pathway Emergency Planning Zone Methodology” (ML24304B034).[3] For clarity, Design Basis Accidents (DBAs) are a subset of the events determined to be LBEs through the NEI 18-04 LMP methodology and are handled differently from how the remainder of the LBEs are handled within this report

Notably, determination of LBE and DBA source terms for input to the EMs in the radiological release consequences methodology is outside the scope of this TR. The methodology to determine source terms for anticipated Natrium LBEs and DBAs is described in the TerraPower radiological source term methodology TR NAT-9392 (renumbered from TP-LIC-LET-0093), “Radiological Source Term Methodology Report.”[4] For example, section 3.3, “Evaluation Model Inputs,” of the TR describes the inputs to the LBE EM, which include information related to the LBE source term releases to the environment and site information. TR table 3-1, “Listing of Licensing Basis Event Evaluation Model Inputs,” lists the model input items for which the specific values are developed through other methodologies. TR section 4.1, “Objective and Scope,” similarly indicates that the determination of the DBA radiological source terms is outside the scope of the TR.

2.0 STAFF EVALUATION

2.1 Licensing Basis Event Evaluation Model

TR section 3.1, “Objective and Scope,” states that the objective of the LBE EM is to determine, through a probabilistic approach, the radiological consequences of an LBE for which a representative source term has been determined. The TR states that the LBE EM is intended to be used by the applicant referencing the TR in the LMP methodology to address the 10 CFR 50.34(a)(4) requirement to provide, in part, a preliminary analysis and evaluation of the design and performance of SSCs. As described in NEI 18-04, the LMP methodology uses information from a facility-specific PRA, including consequences. The radiological source term treated in this EM defines the airborne radionuclides released from the proposed Natrium power plant design to the environment as the result of an LBE. Following the release of airborne radionuclides to the environment, this EM considers the transport of radionuclide plume segments through the atmosphere and determines the resultant consequences of exposure to the released radionuclides. The TR LBE EM analyses will produce the following radiological consequence quantities:

[3] TR NAT-3056 is undergoing separate NRC staff review. NRC approval of TR NAT-9391, if appropriate, does not affect NRC approval or denial of TR NAT-3056.
[4] TR NAT-9392 is undergoing separate NRC staff review (ML24261B944). NRC approval of TR NAT-9391, if appropriate, does not affect NRC approval or denial of TR NAT-9392.

- TEDE to a receptor (i.e., adult individual) at the exclusion area boundary (EAB) for a 30-day exposure to the release plume and ground contamination, determined at the 5th and 95th percentile as well as the mean value.
- Integrated plant risk as the following:
  - Average individual risk of early fatality within 1 mile of the EAB,
  - Average individual risk of latent cancer fatality within 10 miles of the EAB, and
  - Probability of exceeding 100 mrem TEDE at the site boundary.

Because the LBE EM addresses the PRA-related consequence analysis information needs for the LMP methodology, the NRC staff used information in RG 1.247 on PRA consequence analysis to aid in the review and evaluate completeness of the methodology. Specifically, the NRC staff referred to section C.1.3.17, "Radiological Consequence Analysis Probabilistic Risk Assessment Element" of RG 1.247. As discussed in RG 1.247, the PRA analysis elements for a radiological consequence analysis are the following:

- radionuclide release characterization;
- site characterization;
- meteorological data analysis;
- atmospheric transport and diffusion analysis;
- protective action analysis;
- dosimetry;
- health effects analysis;
- economic factors; and
- conditional consequence quantification.

The NRC staff reviewed the LBE EM described in TR section 3 and determined that section 3 contained sufficient information to address the radiological consequence analysis PRA elements detailed in section C.1.3.17.

TR section 3.4, "Computational Model," states that the LBE EM determination of radiological consequences is performed using WinMACCS version 4.1.0,[5] or WinMACCS version 4.2.0.[6] WinMACCS is the Windows-based interface and framework for performing analyses with MELCOR Accident Consequence Code System (MACCS) computer code. MACCS is a fully integrated, engineering-level computer code developed at Sandia National Laboratories (SNL) for the NRC. MACCS simulates the impact of severe accidents at nuclear power plants and other nuclear facilities on the surrounding environment. The NRC staff also reviewed the LBE EM's use of MACCS to determine radiological consequences of an LBE source term. This review included all associated inputs and model parameters, technical rationale, and risk metrics, along with other pertinent details associated with MACCS model execution for the purposes of evaluating radiological release consequences for the proposed Natrium SFR nuclear power plant design.

SE sections 2.1.1, "Radionuclide release characterization," through 2.1.9, "Conditional consequence quantification," provide a brief description of and the NRC staff's evaluation of

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[5] SAND2022-7112, "MACCS (MELCOR Accident Consequence Code System) User Guide – Version 4.0, Revision 1," Sandia National Laboratories, 2022.
[6] SAND2023-01315, "MACCS User Guide – Version 4.2," Sandia National Laboratories, 2023.

each radiological consequence PRA analysis element outlined in RG 1.247, including the TR discussion on the use of MACCS.

2.1.1 Radionuclide release characterization

As stated in RG 1.247, section C.1.3.17, the objective of the radionuclide release characterization is to identify the attributes of the radionuclide release needed to evaluate radiological consequences. TR section 3.5, "Adaption of Release Matrix to MACCS," describes the methods to prepare the LBE release information coming from the radiological source term methodology to provide the needed inputs to the MACCS consequence calculation code. TR table 3-1 states that the term "release matrix" refers to the time dependent, nuclide-specific release of airborne radionuclides to the environment. The NRC staff's findings are given below for each of the topics comprising the adaptation of the release matrix for use in MACCS in subsections to TR section 3.5.

TR section 3.5.1, "Isotope Sensitivity Method," describes the LBE EM screening approach to ensuring that all risk-significant isotopes are included in the radiological consequence analysis through an isotope sensitivity analysis. **[[**

]] The TR methodology use of DCFs from Federal Guidance Report (FGR) 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," and FGR 12, "External Exposure to Radionuclides in Air, Water, and Soil,"[7] is consistent with the guidance in RG 1.183 for determining TEDE and is therefore acceptable. The screening approach also includes iterative MACCS runs to identify any pseudostable nuclides needed to terminate decay chains and to be added as MACCS input to complete the calculation. Therefore, the NRC staff determined that the screening approach modeling of radionuclide characteristics and biological effects is consistent with the determination of TEDE as defined in 10 CFR 50.2, "Definitions" and is therefore acceptable.

TR section 3.5.1.2, "General Isotope Sensitivity Results," applies the screening method to sample Natrium core inventories to determine a set of important radionuclides applicable to any LBE source term that is representative of release from the proposed Natrium reactor core. This resulted in the list of **[[ ]]** in TR table 3-3, "Natrium Release Isotopes Selected for MACCS Calculations," which represents **[[**

]] As stated in TR section 3.5.1.2, the TR table 3-3 list of radionuclides is based on sample core inventories and assumed effective release fractions and is only applicable to core damage events. The list of isotopes is not taken from the TerraPower radiological source term TR, but instead is given as a standard set that is anticipated to represent the proposed Natrium design radionuclides at risk of release and was found acceptable by the NRC staff through its engineering judgment. If a source term is input to the LBE EM that represents a significantly different inventory or effective release fractions than the ones analyzed, the methodology described in TR sections 3.5.1 and 3.5.1.1, "Pseudostable Radionuclides," will be applied to develop an applicable set of important isotopes.

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[7] https://www.epa.gov/radiation/federal-guidance-report-no-11-limiting-values-radionuclide-intake-and-air-concentration

The NRC staff determined the screening approach described in TR section 3.5.1 is acceptable, because the isotope sensitivity calculation method used for determining the relative importance of including a given radionuclide in the radiological consequence analysis considers the radiological half-life, biological hazard, and relative abundance of the radionuclides in the core which is anticipated to result in a smaller list of radionuclides in the assessment without unacceptable loss in accuracy in dose and radiological risk results. The NRC staff determined that the iterative approach to determining the need for pseudostable radionuclide addition (e.g., radionuclides terminating decay chain) is also acceptable because it is consistent with how the guidance in RG 1.247 addresses radionuclide release characterization, and therefore, demonstrates appropriate characterization of source terms.

TR section 3.5.2, "Adaptive Plume Algorithm," describes the LBE EM approach to modeling of radionuclide releases to the atmosphere over time (plume segments) within the MACCS calculation. The TR indicates that the adaptive plume algorithm was developed because the release matrix input to the LBE EM may include a large number of timesteps to model the release of radionuclides to the environment while version 4.1.0 of the MACCS code can only model up to 500 plume segments, requiring a consolidation in time to ensure the entire release is modeled adequately.

During the regulatory audit, the NRC staff asked for information to understand the adaptive plume algorithm as implemented in MACCS and its effect on the modeling of the plume radionuclide concentration. Specifically, the NRC staff audited TerraPower's supporting study of the sensitivity of the dose result at the EAB to the LBE EM adaptive plume algorithm plume segment durations. The audited information confirmed the NRC staff's understanding that modeling plume segments with longer time frames would likely result in less dispersion and therefore more conservative total dose results because the plume concentration, dispersion and heading are all held constant over the time period for the plume segment. The sensitivity study shows that doses are not significantly sensitive to varying plume segment duration in general. Therefore, the NRC staff determined that use of the adaptive plume algorithm is acceptable because it would likely result in conservative dose results and results have low sensitivity to the number of plume segments.

2.1.2 Site characterization

As stated in RG 1.247, section C.1.3.17, the objective of the site characterization is to provide information on the population distribution and patterns of land use and land cover in the vicinity and region of a site to a distance of 80 kilometers or 50 miles. TR section 3.6.4, "Plant Area," indicates that site-specific population distribution information is user input to MACCS. The LBE EM states that instead, a uniform population distribution may be used if it is shown to be conservatively representative, i.e., results in more limiting consequences than the site-specific population distribution gives when used in the LBE EM. The TR also states that the area modeled in MACCS should be larger than the area for which consequences are determined to avoid the influence of boundary conditions. Data on land use and land cover information in the vicinity and region of a site is not provided as an input.

The NRC staff determined the LBE EM treatment of site characterization is acceptable because land use information has a negligible impact on the calculation of dose quantities, the use of a uniform population will be shown to be conservative, and the approach is consistent with previous NRC staff use of the MACCS code in reactor safety studies and the discussion of consideration of inputs for analyses using the MACCS code, as described in NUREG/CR-7270, “Technical Bases for Consequence Analyses Using MACCS (MELCOR Accident Consequence Code System)” (ML22294A091).

2.1.3 Meteorological data analysis

As stated in RG 1.247, section C.1.3.17, the objective of the meteorological data analysis is to evaluate and select the meteorological data used for the atmospheric transport and diffusion analysis. As noted in the MACCS user manual, the MACCS code requires at least one full annual cycle of hourly meteorological data as input to the atmospheric transport and dispersion model. TR table 3-1, item 3.7 identifies that the LBE EM requires input meteorological data including wind speed and direction, stability category, rain rate, and mixing height that is representative of weather conditions at the proposed Natrium power plant over the most limiting year (365 days). The NRC staff notes that this is acceptable consistent with previous NRC staff use of the MACCS code in reactor safety studies and the discussion of consideration of inputs for analyses using the MACCS code, as described in NUREG/CR-7270.

As described in TR section 3.6.1, “Data File Specifications,” in lieu of site-specific meteorological data, the user of the LBE EM may opt to use a generic meteorological data file if user shows the data to be conservatively representative of the site, i.e., results in more limiting radiological consequences than using site-specific data in the LBE EM does. Many relevant regulations reference site-specific meteorological data. In discussing the meteorological data analysis, RG 1.247 notes that the characteristics and attributes to achieve the objectives of the meteorological data analysis element are “[f]or PRAs performed prior to selecting a proposed site, postulated meteorological data . . . that are representative of a reasonable number of sites that have been or may be considered.” Although this TR is not a PRA, as noted above, the TR states that the LBE EM is intended to be used by an applicant referencing the TR in the LMP methodology, which uses information from a facility-specific PRA. Therefore, the NRC staff views the TR discussion of the methodology as the sort of analysis contemplated in the above-quoted language.

TR section 3.6.1 states that the generic meteorological data file is based on the Electric Power Research Institute (EPRI) Advanced Light Water Reactor Utility Requirements Document (URD)[8] that was developed using conservative weather characteristics from 91 U.S. reactor sites documented in NUREG/CR-2239, “Technical Guidance for Siting Criteria Development” (ML072320420). The NRC staff previously evaluated the meteorological data described in Annex B of the URD (revisions 1 through 5), for use in reactor licensing as documented in NUREG-1242, “NRC Review of Electric Power Research Institute's Advanced Light Water Reactor Utility Requirements Document” (ML100610048). In NUREG-1242, the NRC staff discussed that the use of the URD Annex B meteorological data as a standardized set of meteorological site data is reasonable for the limited purpose of demonstrating that the design goal for dose at the site boundary has been met. The NRC staff notes that LMP uses for calculation of dose at the EAB are similar to the uses noted in the URD with respect to completeness of the data set. Given that the site information in both the URD and NUREG/CR-2239 were taken from reactor sites located within the contiguous U.S., the data may not be applicable to conditions in locations outside of the contiguous U.S. Therefore, the NRC staff imposes limitation and condition 1 described later in this SE, which limits the use of the TR to

[8] EPRI 3002003129, “Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document (URD), Revision 13,” EPRI, 2014.

sites within the contiguous U.S., with respect to the generic meteorological data file based on the URD. With limitation and condition 1, the NRC staff determined that the meteorological data in the TR LBE EM are representative of a reasonable number of sites in the contiguous U.S. that may be considered. Therefore, the TR LBE EM is acceptable because it follows the RG 1.247 guidance on site characterization performed prior to selecting a proposed site. The NRC staff notes, however, that this approval does not change the relevant regulations referencing site-specific meteorological data. It also does not constitute approval of the use of generic data instead of site-specific data in future analyses when addressing relevant regulations, including 10 CFR 50.34. Applicants referencing this TR should consider how this methodology may need to incorporate additional information in order to satisfy the regulatory requirements.

TR section 3.6.2.2, "Weather Sampling," describes the use of meteorological data in the MACCS computation to develop weather trials and capture the inherent uncertainty in the weather conditions assumed for the LBE radiological consequence analysis. The LBE EM specifies that the MACCS computation take non-uniform random samples of weather data from the meteorological data file in 36 weather bins. The NRC determined that the use of random weather sampling to assess uncertainty is acceptable because it is consistent with guidance on radiological consequence analysis for PRAs in RG 1.247.

2.1.4 Atmospheric transport and diffusion analysis

As stated in RG 1.247, section C.1.3.17, the objective of the atmospheric transport and diffusion analysis is to perform an evaluation that provides time dependent air and ground concentrations resulting from a release of radioisotopes. TR section 3.6.2, "Atmospheric Dispersion," describes the LBE EM use of the Gaussian plume segment model in MACCS. The NRC staff determined the use of the MACCS Gaussian plume segment model is acceptable because it is based on Gaussian plume dispersion algorithms found acceptable for use in other regulatory contexts requiring evaluation of atmospheric dispersion, as described in RG 1.145 and RG 1.249. However, the NRC staff also notes that the atmospheric dispersion models described in the accident-related guidance referenced above are based on weather conditions that are expected in the contiguous U.S. (i.e., the lower 48 states where the developmental field studies were conducted). Certain model algorithms may not be applicable to sites subject to more extreme weather or persistent cold conditions. See for example, the discussion in RG 1.249, regulatory position 2.1, "Meteorological Data Input." Therefore, consistent with the discussion above in SE section 2.1.3, the NRC staff also imposes limitation and condition 1 described later in this SE, which limits the use of the TR deterministic and probability-based atmospheric dispersion models to sites within the contiguous U.S. unless technical justification for their applicability is provided. Further, consistent with the discussion in SE section 2.1.3, this SE does not constitute approval of the use of generic meteorological data instead of site-specific meteorological data in future analyses when addressing relevant regulations, including 50.34.

The NRC staff evaluated the TR section 3.6.2 description of the MACCS input selections that define the computational model with respect to atmospheric dispersion modeling. The LBE EM includes the selection of dispersion parameters appropriate to the characteristics of the area and distance ranges under consideration. Nearfield effects, such as elevated releases of radioactive material; building wake effects such as wake-induced downwash and enhanced diffusion due to nearfield wake-induced turbulence; plume meander; and plume rise, are adequately characterized. The use of the Ramsdell and Fosmire model incorporated into

MACCS is consistent with other NRC-developed dispersion codes used for nearfield dispersion analysis, such as the ARCON[9] code.

In the LBE EM, dispersion parameters are supplied in the form of a Eimutis and Konicek (E&K) lookup-table based on the selection of the plume meander model for nearfield evaluation (i.e., atmospheric transport and dispersion within about 500 meters). This is consistent with the recommendation in SAND2021-6924, "Implementation of Additional Models into the MACCS Code for Nearfield Consequence Analysis" (ML21257A120), which describes how to use MACCS models, that the E&K parameterization of the Pasquill-Gifford diffusion curves, implemented via lookup-table, should be used to model nearfield dispersion. During the regulatory audit, the NRC staff confirmed that the diffusion coefficients specified in the LBE EM are the same as typically used in dispersion models acceptable to the NRC. The NRC staff notes that since the dispersion parameter input is implemented via a lookup-table rather than a power law, the propagation of uncertainties may be challenging. However, the NRC staff determined that the use of the lookup-table in the LBE EM is acceptable without an explicit assessment of uncertainty, because it is based on a widely used approximation to the Pasquill-Gifford diffusion curves, is consistent with Ramsdell and Fosmire model used in the EM, and the use of the E&K parameterization is consistent with implementation in NRC-developed atmospheric dispersion codes, as well as technical guidance for MACCS in NUREG/CR-7270

The deposition of airborne material on the ground by wet and dry deposition and the resulting depletion of the airborne material with downwind distance are discussed in TR section 3.6.3, "Plume Deposition." The LBE EM deposition modeling in dry conditions is dependent on the deposition velocity and is radionuclide-specific and dependent on aerosol size. Wet deposition is modeled according to the weather trial considered. Algorithms and coefficients used to estimate wet and dry deposition are based on particle sizes as described in the MACCS user guide description of the models. TR table 3-1, item 3.3 identifies that the element-specific aerosol particle size distribution of all radionuclides considered in each release matrix is a user input to the LBE EM. The NRC staff determined that the deposition modeling is acceptable because it is consistent with reactor risk analyses using the MACCS code described in NUREG/CR-7270.

TR section 3.6.3 also describes the LBE EM's use of the MACCS CHRONC module to evaluate the individual risk of latent cancer from long-term exposure to radionuclides deposited on the ground. The LBE EM models the effects of weathering on the ground contamination concentration, as well as resuspension of the radionuclides to the atmosphere by defining values to calculate weathering factors and resuspension coefficients to affect the radionuclide exposure in the groundshine and inhalation transport pathways. The NRC staff determined this modeling of long-term ground contamination is acceptable because it is consistent with reactor risk analyses using the MACCS code described in NUREG/CR-7270.

2.1.5 Protective action analysis

As stated in RG 1.247, section C.1.3.17, the objective of the protective action analysis is to characterize the impact of mitigation measures such as evacuation, sheltering, relocation, and interdiction of land, food, or water on doses resulting from releases of radioisotopes. TR section 3.6.5, "Protective Actions," describes the conservative approach taken for early phase

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[9] Pacific Northwest National Laboratory, "ARCON 2.0 User's Guide," dated May 24, 2021 (ML22004A219).

protective actions in the MACCS calculations, in which no credit is taken for ingestion of potassium iodide or evacuation. In other words, the TR LBE EM conservatively considers no evacuation in consequence calculations. The LBE EM describes that the relocation model in MACCS is effectively turned off by setting the relocation dose to an unphysically high value. The NRC staff determined this approach is acceptable because it results in a conservative determination of the radiological consequences.

TR section 3.6.5 also describes the LBE EM use of the MACCS CHRONC module to evaluate the individual risk of latent cancer from long-term exposure to radionuclides deposited on the ground. The LBE EM models the intermediate- and long-term phase protective actions such as land decontamination and condemnation based on reaching specified dose levels. The NRC staff determined that the description of the modeling of intermediate- and long-term phase protective actions is acceptable because it is consistent with recommendations in NUREG/CR-7270 and reflects the relevant Environmental Protection Agency (EPA) Protective Action Guides (PAGs).[10] In the regulatory audit TerraPower clarified that dose reduction factors associated with occupancy of structures or vehicles will be described, and their basis documented in the analysis supporting a license application, not in the TR methodology. TerraPower also stated in the audit that the values would generally be consistent with NUREG/CR-7270. The NRC staff will evaluate this in its review of a future license application referencing the TR methodology.

2.1.6 Dosimetry

As stated in RG 1.247, section C.1.3.17, the objective of the dosimetry PRA analysis element is to identify the analyses needed to estimate doses to offsite populations, arising from airborne and deposited radioisotopes. The TR discusses dosimetry in section 3.6.6., "Dosimetry," with supporting information in sections 3.1," Objective and Scope," 3.2, "Regulatory Requirements and Guidance," and 3.6.7, "Radiological Consequences." The TR states that radiological consequences in the LBE EM are modeled in the MACCS code in terms of organs of risk. These are organs for which DCFs are provided in the MACCS DCF data file prepended with either "A" to denote an acute dose or "L" to denote a lifetime dose. The organs of risk considered in the LBE EM are listed in TR table 3-5, "Listing of Organs of Risk for MACCS Calculations," including an effective organ to model the TEDE. The NRC staff determined that the information on organs of risk is acceptable because it is consistent with reactor risk analyses using the MACCS code described in NUREG/CR-7270, as well as the guidance in RG 1.183 on use of DCFs from FGR 11 and FGR 12 to calculate TEDE.

The risk of early fatality is computed using the hazard function given by equation 3-35 of the MACCS user guide. The factors for each organ considered in the LBE EM, to be used in equation 3-35 from the MACCS user guide, are given in TR table 3-6, "Early Fatality Parameters for MACCS Calculations." The MACCS code is capable of computing latent cancer fatality risk with a linear-quadratic model. The quadratic portion of this model is disabled by specifying a linear factor of one, a quadratic factor of zero, and a dose limit for the linear-quadratic relationship of zero for all organs. The risk of latent cancer fatality is then computed from the fraction of the population that is susceptible to the latent cancer, the lifetime risk factor for a

[10] 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.

cancer fatality, and the dose and dose-rate effectiveness factor. The values for these parameters are listed in TR table 3-7, “Latent Cancer Fatality Parameters for MACCS Calculations.” The NRC staff determined the information on calculation of the risk of early fatality and risk of latent cancer fatality, including the parameter input values listed in TR tables 3-6 and 3-7, is acceptable because it is consistent with the reactor risk analyses using the MACCS code, as described in NUREG/CR-7270.

The TR description indicates that all relevant short- and long-term exposure pathways are identified and included as appropriate for the results of interest. The TEDE is computed considering inhalation dose, cloudshine, and groundshine. The NRC staff determined the calculation of TEDE as described in the LBE EM is acceptable because all pathways are identified and considered, as appropriate, in the MACCS calculation, consistent with the NRC regulatory guidance in RG 1.183 for estimating TEDE.

With respect to the calculation of individual risk of early fatality and latent cancer, the age and gender characteristics of the offsite population are not clearly identified in LBE EM, but dose coefficients consistent with FGR 13, “Cancer Risk Coefficients for Environmental Exposure to Radionuclides,” are used. This reflects an age- and gender-averaged adult population. The NRC staff determined the LBE EM calculation for the risk metrics acceptable because the dosimetry is based on FGR 13, which is a recognized information source developed by the EPA as a resource for the federal government.

TR section 3.1 states that the LBE EM consequences should be calculated by the user for a 30-day exposure period to determine the peak individual TEDE at the EAB, the probability of exceeding 100 mrem TEDE at the site boundary, and the average individual risk of early fatality within 1 mile of the EAB. Within the LBE EM, the average individual risk of latent cancer fatality within 10 miles of the EAB is calculated for a 51-year chronic exposure period in addition to the initial 30-day early exposure period. The NRC staff determined the LBE modeling of the exposure periods acceptable because it is consistent with the description in NEI 18-04 of the dose quantity to be compared to the LMP frequency-consequence target, the Quantitative Health Objective (QHO) figures of merit for early fatality risk and latent cancer fatality risk and is reasonable for the evaluation of the cumulative probability per plant-year of exceeding the 100 mrem TEDE at the site boundary as described in the LMP.

2.1.7 Health effects analysis

As stated in RG 1.247, section C.1.3.17, the objective of the health effects analysis is to assess the risk of early or latent health effects, either fatal or nonfatal, or both, arising from acute and chronic exposure to released radioisotopes. TR section 3.1 lists the four radiological consequences assessed in the LBE EM:

- The TEDE dose received by a receptor on the EAB considering the dose due to inhalation of airborne radionuclides, radiation shine from airborne radionuclides, and radiation shine from radionuclides deposited on the ground, determined at the 5th and 95th percentile as well as the mean value.
- The probability of exceeding 100 mrem TEDE at the site boundary.
- The average individual risk of early fatality within 1 mile of the EAB.
- The average individual risk of latent cancer fatalities within 10 miles of the EAB.

Additional information on the health effects modeling is given in TR sections 3.6.6, “Dosimetry,” and 3.6.7, “Radiological Consequences.” The LBE EM dose-response models use information from FGR 13 to estimate the risk of health effects. The LBE EM is based on the linear no-threshold (LNT) dose-effect model that serves as the basis for the NRC's radiation protection regulations. The NRC staff determined the LBE EM acceptable with respect to the health effects analysis because the list of cancer fatality sites in the human body is consistent with FGR 13 and the list of early fatality health effects is consistent with those identified in NRC reactor risk studies with consequence analyses which cover similar situations (i.e., NUREG-1150[11] and the State-of-the-Art Reactor Consequence Analyses (SOARCA)[12]), as well as in NUREG/CR-7270. In addition, the NRC staff determined the use of the MACCS code in the LBE EM to be acceptable because the MACCS code incorporates dose-response models from FGR 13.

2.1.8 Economic factors

As stated in RG 1.247, section C.1.3.17, the objective of the economic factors PRA analysis element is to assess the economic impact of releases of radioisotopes, including the economic impact of protective actions taken to limit exposure to released material. However, this PRA analysis element is not applicable to the evaluation of the LBE EM since the figures of merit in the LMP do not include economic costs. The LMP methodology, as endorsed in RG 1.233, does not use economic factors or cost-benefit analysis to determine events, classify SSCs, or evaluate the adequacy of defense-in-depth, consistent with the requirements in 10 CFR 50.34 which it addresses.

2.1.9 Conditional consequence quantification

As stated in RG 1.247, section C.1.3.17, the objective of the conditional consequence quantification is to integrate the models and data developed in the preceding technical elements to quantify results of interest. The NRC staff notes that the LBE EM uses the MACCS code for the purposes it was developed and well within the limits of its applicability as described in numerous published reports and documentation accompanying the code. The NRC staff determined that the MACCS model inputs and accompanying data files and specifications are acceptable for use in the LBE EM because they are well documented in the TR and are consistent with sample problems supplied with MACCS, input parameter guidance (i.e., NUREG/CR-7270), and accepted practices from published literature. Safety analysis code verification and validation is out of scope for the review of this TR.

The TR does not provide sufficient information for the NRC staff to determine if sources of model and parameter uncertainty for each element of the analysis are identified. However, based on its engineering judgment, the NRC staff determined that the uncertain parameters that contribute significantly to radiological consequences were analyzed and conservatively bounding values were prescribed in the LBE EM. TR section 3.7, “MACCS Analysis Uncertainty Methodology,” describes the LBE EM uncertainty methodology, including parameter sensitivity and uncertain parameter treatment. The TR states that the impact of significant sources of model and parameter uncertainty on results of interest were analyzed and that sensitivity analyses will be used to identify sensitive parameters, which will be addressed using Monte

[11] NUREG-1150, “Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants,” NRC, 1990 (ML120960691).
[12] NUREG-1935, Parts 1 and 2, “State-of-the-Art Reactor Consequence Analyses (SOARCA) Report,” NRC, 2012 (ML12332A053).

Carlo methods to sample from a probability distribution, in the analyses performed in support of future license applications that reference the TR methodology. The TR identifies NUREG/CR-7270 as one potential source of probability distributions for many MACCS input parameters. It also lists other sources that are consistent with NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making," (ML17062A466). The TR also states that, in order for an entity to use this TR, for the treatment of uncertainty with regard to the source term input, that entity will follow one of the methods described in TR section 3.7, depending on the treatment of uncertainty utilized in the development of the source term. The NRC staff determined the treatment of uncertainty is acceptable because it is consistent with the NRC's approach in SOARCA and established approaches to uncertainty analyses (i.e., NUREG-1855).

TR section 3.6.2.2, "Weather Sampling," describes the use of weather sampling to quantify the effect of the variability in meteorological conditions on the results of interest (e.g., TEDE at the EAB), as reflected in the input parameters related to meteorological observations. The LBE EM addresses the uncertainty in the weather in combination with the variability in meteorological conditions by specifying the use of meteorological data for the most limiting year if using site-specific data, as stated in TR table 3-1, Item 3.7. TR section 3.6.7 describes the use of MACCS outputs to estimate the mean, 5^{th}, and 95^{th} percentile results. The NRC staff determined that weather sampling approach is acceptable because it is consistent with the NRC's approach in probabilistic consequence analyses (i.e., SOARCA).

2.1.10 NRC staff overall determinations on the LBE EM

Based on its review as discussed above, the NRC staff determined that the LBE EM is acceptable, subject to limitation and conditions described later in this SE, because it provides sufficient information for the user of the TR methodology to provide estimates of LBE radiological consequences for use in the LMP methodology consistent with the non-light water reactor radiological consequence analysis PRA elements detailed in section C.1.3.17 of RG 1.247. The NRC staff also determined that the LBE EM consequence analysis results when used in the LMP consistent with RG 1.233 are sufficient to address the analysis requirements in 10 CFR 50.34(a)(4). In addition, the NRC staff determined that the LBE EM identifies a PRA consequence analysis tool (MACCS) which is an acceptable tool for use in this EM because it is an NRC-developed, widely used PRA analytical tool specific to consequence analysis.

2.2 Design Basis Accident Evaluation Model

TR section 4, "Design Basis Accident Evaluation Model," describes the TerraPower Natrium EM for DBA radiological consequence analysis. The TR states that the DBA EM provides a conservative, deterministic approach to determine the dose consequences of DBAs to be used in the LMP methodology. The dose consequences a future applicant would determine by using this EM are the highest TEDE dose received over any 2-hour period by a receptor on the EAB considering contributions due to inhalation and radiation shine from airborne radionuclides (i.e., inhalation and submersion dose) and the 30-day TEDE dose received by a receptor at the outer LPZ boundary also considering inhalation and submersion dose. Applicable criteria associated with the dose consequences are in 10 CFR 50.34(a)(1)(ii)(D)(1) and 10 CFR 50.34(a)(1)(ii)(D)(2) which specify a limiting dose of 25 rem TEDE for each DBA.

TR section 4.1, "Objective and Scope," states that the DBA source terms are derived from the design basis events (DBEs) evaluated in the LBE EM (TR section 3) by only taking credit for safety-related SSCs to mitigate dose consequences.

TR section 4.1 also states that the DBA EM does not include explicit treatment of atmospheric transport to receptor location. Instead, entities relying on this report would determine atmospheric dispersion factors separately and use them with the DBA EM. Therefore, methods to estimate atmospheric dispersion factors for evaluation of DBAs are outside the scope of the TR. The NRC staff will evaluate whether the applicants have acceptably used the referenced TR methodologies for the specific methods used to calculate DBA radiological source terms and atmospheric dispersion factors used as input to the DBA consequence analysis during the review of an application that references the TR and implements the DBA EM. Though outside the scope of the TR, the NRC staff anticipates that the atmospheric dispersion factors used in the DBA radiological consequence analyses will be shown to be representative of the specific site in the application that implements this TR.

TR section 4.3, "Evaluation Model Inputs," provides information on the inputs into the DBA EM radiological consequences methodology. Table 4-1, "Listing of Design Basis Accident Evaluation Model Inputs," states that the inputs are the time-dependent, nuclide-specific release of airborne radionuclides to the environment (release matrix) and release-specific atmospheric dispersion factors from the most limiting locations for the EAB and LPZ. TR section 4.3 also re-iterates that the determination of the DBA radiological source term and atmospheric dispersion factors used as input with DBA EM are outside the scope of the TR.

TR section 4.4, "Computation Model," states that the Released Radionuclide Consequence Analysis Tool (RRCAT) code version 1.0 is used to determine inhalation and submersion doses. The TR executive summary and TR section 4.4 state that the RRCAT code was developed to accept the radiological source term from the TerraPower radiological source term methodology as input and calculate doses equivalently to the NRC-developed RADTRAD[13] code, which is used by the NRC staff to evaluate DBA radiological consequence analyses. TR section 4.4 also states that RRCAT was used because it allows for timestep-specific releases, which RADTRAD is not capable of. The TR states that the models contained in RRCAT can calculate dose equivalently to RADTRAD since it follows the guidance contained in RG 1.183, uses DCFs from FGR 11 and 12, and uses half-life and decay progeny from FGR 12.

The NRC staff reviewed information in TR section 4 and supporting audit documentation on the RRCAT computer code to determine if the use of RRCAT is appropriate for DBA dose consequence analysis. Through audit of the RRCAT documentation, the NRC staff confirmed that the models within RRCAT are used to calculate receptor dose from airborne plume sources from inhalation and submersion in the release plume consistent with the guidance in RG 1.183 and similar to the RADTRAD code. TR section 6.1 also indicates that the RRCAT code is controlled through the user's approved quality assurance program in accordance with 10 CFR appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." The code requires the input of time-dependent radioisotope release information, nuclear data, DCFs, and **[[ ]]**. The NRC staff audit of the RRCAT documentation confirmed that the RRCAT computer code employs the same dose estimation models used by RG 1.183 and uses the breathing rates and DCFs consistent with RG 1.183, as described in TR section

[13] NUREG/CR-7220, "SNAP/RADTRAD 4.0: Description of Models and Methods," Information Systems Laboratory, Inc., 2016 (ML16160A019).

4.4. The NRC staff reviewed the RRCAT code only to determine if it implements the DBA EM consistent with the TR description and makes no conclusion as to the acceptability of the RRCAT code itself.

TR section 4.5, “Atmospheric Dispersion,” describes the specific input of time-averaged atmospheric dispersion factor values to ensure that the most limiting dose is calculated. TR section 4.6, “Offsite Dose Consequences,” discusses the use of assumed offsite breathing rates, as well as accident time periods from RG 1.183. The NRC staff determined that the calculation methods described in TR sections 4.5 and 4.6 are acceptable because they are consistent with RG 1.183 for DBA radiological consequence analysis assumptions and inputs.

Based on its review as discussed above, the NRC staff determined that the DBA EM described in the TR is acceptable because it provides sufficient information for the user of the methodology to calculate DBA radiological consequences for use in the LMP methodology, consistent with the DBA radiological consequence analysis guidance in RG 1.183. Therefore, the TR provides sufficient information such that a user applying the TR could demonstrate compliance with the safety analysis offsite dose criteria in 10 CFR 50.34(a)(1)(ii)(D). In addition, the NRC staff determined that the DBA EM identifies a DBA consequence analysis tool (RRCAT) which provides deterministic dose results and provides information on use of the tool to ensure that the dose results are appropriately representative of the proposed Natrium facility and are consistent with the guidance in RG 1.183.

Though outside the scope of this TR, the NRC staff notes that when dispersion factors are determined, the user should consider the basis for atmospheric dispersion models as discussed above in SE section 2.1.4.

2.3 Control Room Habitability Evaluation Model

TR section 5 describes the TerraPower Natrium EM for control room habitability (CRH) radiological consequence analyses. The TR states that this EM is used to determine the dose consequences required to demonstrate habitability in the CR in conformance with Natrium PDC 19 (ML24283A066).[14] As it relates to the dose criteria for control room radiological habitability analyses, Natrium PDC 19 states, in part: “Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem total effective dose equivalent, as defined in § 50.2 for the duration of the accident.” The specific dose consequences calculated in the CRH EM are the 30-day TEDE dose received by a CR receptor considering inhalation and submersion dose, as well as gamma radiation shine from airborne radionuclides external to the CR, built up on filtration equipment, and held in a compartment before release to the environment. Natrium PDC 19 would be met, in part, by limiting the CR dose consequences to 5 rem TEDE for each source term for which dose consequences are determined with this EM.

TR section 5.3 “Evaluation Model Inputs,” provides a list of inputs as described in TR table 5-1, “Listing of Control Room Habitability Evaluation Model Inputs.” This table states that the inputs to the CRH EM are the time-dependent, nuclide-specific release of airborne radionuclides to the environment, specification of releases as aerosols or vapors, the physical description of the

[14] The NRC staff notes that approval of this TR, if appropriate, does not constitute approval of PDC 19. PDC 19 is outside the scope of this review and will be considered during the review of CP application for applicants referencing this TR.

compartment from which radionuclides are released to the environment, the atmospheric dispersion factors from the release location to each CR air intake location, and the description of the CR including the dimensions, the description of heating, ventilation, and air conditioning systems including all flow paths and in-leakage from the environment and filtration equipment.

Similar to the LBE and DBA EMs, the methods to determine the CRH EM input source terms and dispersion factors are outside the scope of the TR. As noted above in SE section 1.0, the methodology to determine radiological source terms is described in a separate TerraPower topical report TR NAT-9392, which is currently undergoing NRC staff review. NRC staff will evaluate the acceptability of the specific methods used to calculate CR atmospheric dispersion factors, and modeling of the CR used as input to the CRH consequence analysis during the review of an application that references this TR and implements the CRH EM. The NRC staff anticipates that the atmospheric dispersion factors used in the DBA radiological consequence analyses will be shown to be representative of the specific site in the application that implements this TR.

TR section 5.4, "Computational Model," states that the EM will be used to calculate the inhalation and submersion doses delivered to the receptor inside the CR. Like the DBA EM, the CRH EM utilizes the RRCAT code to calculate the CR doses. However, the CRH EM involves use of the **[[ ]]** with some additional methodology steps to result in evaluation of **[[ ]]** To understand if the use of **[[ ]]** and the additional factors to account for **[[ ]]** is appropriate for CR dose analysis, the NRC staff evaluated the information contained in TR section 5, along with an example calculation made available during the regulatory audit to enhance understanding of the TR discussion. The NRC staff's evaluation of the RRCAT code is described above in SE section 2.2 for the DBA EM. The NRC staff audit of the RRCAT documentation also confirmed that the RRCAT computer code employs the same dose estimation models used by the NRC-developed RADTRAD code and is consistent with guidance on CR dose analyses in RG 1.183, as described in TR section 5.4. The NRC staff reviewed the RRCAT code only to determine if it implements the CRH EM consistent with the TR description and makes no conclusion as to the acceptability of the RRCAT code itself.

TR section 5.5, "Shine Dose," describes the CRH EM proprietary approach to calculating shine dose to the CR receptor. As discussed in TR section 5.4, **[[ ]]**

The CRH EM utilizes **[[ ]]** to calculate gamma shine dose to the most limiting CR receptor location. **[[ ]]**.

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15 **[[ ]]**
16 **[[ ]]**

The NRC staff notes that **[[**

]] Therefore, the NRC staff determined that the use of these computer codes is acceptable for the purpose described in the CRH EM. In the regulatory audit, the NRC staff had access to an example calculation for determination of **[[ ]]**. The audited information showed an example of the use of the CRH EM, including potential inputs based on preliminary Natrium design information and conservative shine dose modeling. The NRC staff used the example calculation to confirm the information provided in the CRH EM method for calculating shine dose in the CR. The NRC staff determined that the method to calculate shine dose in the CR is acceptable because the method produces integrated CR dose results that include inhalation, submersion, and shine pathways using the stated computer codes.

TR section 5.6, "Control Room Dose Consequences," discusses the specific input of time-averaged atmospheric dispersion factor values to ensure that the most limiting dose is calculated, guidance on specifying the CR model assumption inputs, as well as the assumed breathing rate, and CR occupancy factors taken from RG 1.183. The NRC staff determined that the calculation methods described in TR section 5.6 are acceptable because they are consistent with RG 1.183 for CR radiological consequence analysis assumptions and inputs.

TR section 5.7, "Uncertainty Treatment," states that the LMP DBE and major accident source terms are input to the CRH EM to demonstrate conformance with the proposed Natrium PDC 19 CR radiological habitability criterion. The TR states that the proposed Natrium CR is non-safety-related with special treatment (NSRST). The CRH EM accounts for the uncertainty related to the behavior of the NSRST SSCs through use of bounding conservative assumptions to provide a deterministic dose assessment. The TR states that the conservative assumptions should bound realistically expected behavior of CRH EM credited NSRST SSCs. The NRC staff determined that the CRH EM treatment of uncertainty is acceptable because it is anticipated to result in a reasonably conservative estimate of the CR dose based on considering the uncertainty in the expected behavior of the CR by making bounding conservative assumptions. The NRC staff will evaluate the inputs and assumptions used to model the CR and other SSCs that are credited in the CR dose analyses in its review of an application which references this TR to implement the CRH EM.

Based on its review as discussed above, the NRC staff determined that the CRH EM described in the TR is acceptable because it is consistent with the DBA CR radiological consequence analysis guidance in RG 1.183. It also provides sufficient information for the user of the TR methodology to provide estimates of CR radiological consequences to show that the Natrium PDC 19 is met, in part. In addition, the NRC staff determined that the CRH EM identifies **[[**

]] to ensure that the dose results are appropriately representative of a Natrium facility.

Though outside the scope of this TR, the NRC staff notes that when dispersion factors are determined, the user should consider the basis for atmospheric dispersion models as discussed above in SE section 2.1.4.

2.4 Appendix – Adaptation of LBE EM for EPZ Sizing

TR section 8, "Appendix - Adaptation of Licensing Basis Event Evaluation Model to Emergency Planning Zone Sizing," describes minor changes to the LBE EM described in TR section 3 for use in the TerraPower PEP EPZ sizing methodology provided in TR NAT-3056, which is undergoing separate NRC review. These changes ensure that the dose results calculated at the proposed PEP EPZ boundary are relevant for comparison to the PEP EPZ sizing criteria in NAT-3056 which address the PEP EPZ size requirements in 10 CFR 50.33(g)(2). The NRC staff agrees that the changes to the LBE EM MACCS modeling described in TR section 8 would result in the output of mean and 95th percentile TEDE for a 96-hour exposure, and 24-hour acute red bone marrow dose relevant for comparison to the PEP EPZ sizing criteria in NAT-3056. The NRC staff determined that the adapted LBE EM is acceptable because it provides dose results in the form of TEDE to an individual from a 96-hour exposure at various distances to address the PEP EPZ requirement in 10 CFR 50.33(g)(2). The NRC staff also notes that it provides information needed for the TerraPower's PEP EPZ sizing methodology with respect to dose aggregation and evaluation of early deterministic health effects. The NRC staff's determination of the acceptability of the TerraPower PEP EPZ sizing methodology with respect to the requirements in 10 CFR 50.33(g)(2) is currently under review.

LIMITATIONS AND CONDITIONS

The NRC staff identified the following limitations and conditions, applicable to any licensee or applicant referencing this TR.

1. Application of the methodology in this TR with respect to the described deterministic and probability-based atmospheric dispersion modeling analyses and use of generic meteorological data is limited to sites within the contiguous United States unless technical justification for their applicability is provided.

2. The conclusions reached in this SE are not valid if a process other than that described in NEI 18-04 is used to perform the Natrium safety analysis.

CONCLUSION

NRC staff determined that NAT-9391, Revision 0, subject to the limitations and conditions discussed above, provides an acceptable approach to develop analyses to aid in the determination of site-specific radiological release consequences for proposed Natrium reactor designs. Accordingly, the NRC staff concludes that the subject TerraPower TR can be used in developing radiological consequence analyses for DBAs and LBEs in accordance with the regulatory requirements in 10 CFR 50.34(a)(1) and (4), to assess the Natrium CR radiological habitability criteria in PDC 19 provided in accordance with the regulatory requirements in 10 CFR 50.34(a)(3)(i), and to support PEP EPZ sizing analysis in accordance with the regulatory requirements in 10 CFR 50.33(g)(2), for prospective TerraPower Natrium reactor CP or operating license applications under 10 CFR Part 50.

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0	All	Initial Issue. Supersedes TP-LIC-RPT-0005 Rev. 0. Incorporates changes made to address NRC questions during audit review. Changes from previous information marked via change bars.

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ACRONYMS

Acronym	Definition
AOO	Anticipated Operational Occurrence
APM	Adaptive Plume Mesh
BDBE	Beyond Design Basis Event
CCDF	Complementary Cumulative Distribution Function
CR	Control Room
CRH	Control Room Habitability
DBA	Design Basis Accident
DBE	Design Basis Event
DCF	Dose Conversion Factor
DF	Decontamination Factor
DOE	Department of Energy
EAB	Exclusion Area Boundary
ECP	Engineering Computer Program
EM	Evaluation Model
EPRI	Electric Power Research Institute
EPZ	Emergency Planning Zone
F-C	Frequency-Consequence
FGR	Federal Guidance Report
GEH	GE-Hitachi
LBE	Licensing Basis Event
LNT	Linear No Threshold
LPZ	Low Population Zone
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
OQE	Other Quantified Event
PDC	Principal Design Criterion
PEP	Plume Exposure Pathway
QHO	Quantitative Health Objective
RAF	Ramsdell and Fosmire
RG	Regulatory Guide
RRCAT	Released Radionuclide Consequence Analysis Tool
SDCF	Shine Dose Conversion Factor
SFR	Sodium Fast Reactor

Acronym	Definition
SOARCA	State-of-the-Art Reactor Consequence Analyses
SR	Safety-Related
SSC	System, Structure, and Component
TEDE	Total Effective Dose Equivalent
ToR	Topical Report
URD	Utility Requirements Document
U.S.	United States

1 EXECUTIVE SUMMARY

This topical report (ToR) provides three evaluation models (EMs) that will be used to determine the consequences of radiological release source terms developed for the Natrium™[1] sodium fast reactor (SFR) nuclear power plant according to TP-LIC-RPT-0003 Rev. 1, *Radiological Source Term Methodology Report* [1]. The first EM is proposed for the determination of the radiological consequences of three subcategories of licensing basis events (LBEs): anticipated operational occurrences (AOOs), design basis events (DBEs), and beyond design basis events (BDBEs), as well as other quantified events. This EM is referred to as the LBE EM and is described in Section 3. The second EM is proposed for the determination of the dose consequences of design basis accidents (DBAs). This EM is referred to as the DBA EM and is described in Section 4. The third EM is proposed for the determination of dose consequences used to demonstrate control room habitability (CRH). This EM is referred to as the CRH EM and is described in Section 5. The modifications to the LBE EM needed to determine the dose results required for the determination of the size of the plume exposure pathway (PEP) emergency planning zone (EPZ) as described in NAT-3056 Rev. 1, *Topical Report: Plume Exposure Pathway Emergency Planning Zone Sizing Methodology* [2] are described in the Appendix to this ToR.

The LBE EM applies a probabilistic approach to determine the radiological consequences of a given source term considering phenomena related to the atmospheric transport of radionuclides released to the environment and the resultant radiological consequences delivered to receptors at various locations surrounding the plant. These phenomena are accounted for using models implemented in the WinMACCS code [3], referred to as MACCS in this work. The MACCS code input is developed to model radiological releases from the Natrium power plant following the U.S. Nuclear Regulatory Commission (NRC) sample problem provided with the MACCS code identified as the Point Estimate Linear No Threshold (LNT) model and the guidance of NUREG-1935, *State-of-the-Art Reactor Consequence Analyses (SOARCA) Report* [4]. The following radiological consequences are determined using MACCS following the initiation of the LBE:

1. The total effective dose equivalent (TEDE) dose received by a receptor on the exclusion area boundary (EAB) considering the dose due to inhalation of airborne radionuclides, radiation shine from airborne radionuclides, and radiation shine from radionuclides deposited on the ground. This quantity is determined at the 5th and 95th percentile as well as the mean value.

2. The probability of exceeding 100 mrem TEDE as defined above at the site boundary.

3. The average individual risk of early fatality within 1 mile of the EAB.

4. The average individual risk of latent cancer fatalities within 10 miles of the EAB.

The above are the radiological consequences considered in the Nuclear Energy Institute NEI-18-04, *Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development* [5] LBE selection Tasks 7a and 7b. These tasks relate to the Frequency-Consequence (F-C) Target and quantitative health objectives (QHOs) which are presented in the safety analysis report. The generation of the F-C Target and QHOs is outside the scope of this report. Only the determination of the radiological consequences required to generate those criteria is described.

The DBA EM applies a deterministic approach to determine the dose consequences of a given source term. In this EM, the atmospheric transport of radionuclides released to the environment to receptor locations is accounted for using atmospheric dispersion factors developed separately from this work.

[1] a TerraPower & GE-Hitachi technology

The dose delivered to offsite receptors is calculated directly with these dispersion factors. Model parameters are developed following Regulatory Guide (RG) 1.183 Rev. 1, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors* [6] as applicable to determine the following dose consequences for the 30-day period following the initiation of the DBA:

1. The highest TEDE dose received over any 2-hour period by a receptor on the EAB considering the dose due to inhalation of and radiation shine from airborne radionuclides, referred to in this work as inhalation and submersion dose.

2. The 30-day TEDE dose received by a receptor on the outer boundary of the low population zone (LPZ) also considering inhalation and submersion dose.

These are the dose consequences required to demonstrate compliance to 10 CFR 50.34, *Domestic Licensing of Production and Utilization Facilities, Contents of applications; technical information* [7] limits. All DBA dose consequences are determined conservatively assuming that only safety related systems, structures, and components are available to mitigate them.

The CRH EM applies a deterministic approach similar to the DBA EM with additional phenomena considered to determine the contamination of the control room (CR) atmosphere and the radiation shine delivered to CR receptors. Phenomena related to the contamination of the CR atmosphere are accounted for using models originally described in NUREG/CR-7220, *SNAP/RADTRAD 4.0: Description of Models and Methods* [8], referred to as RADTRAD in this work. The RADTRAD code was developed for the NRC and is maintained through the NRC sponsored Radiation Protection Computer Code Analysis and Maintenance Program. The models described for determination of the CR receptor dose due to atmospheric contamination following the release of radionuclides to the environment in the RADTRAD code are implemented equivalently in the Released Radionuclide Consequence Analysis Tool (RRCAT) code version 1.0, referred to as RRCAT in this work. The RRCAT code was developed to accept the radiological source term determined by the Radiological Source Term Methodology as input and to compute doses equivalently to the RADTRAD code. Additionally, the RRCAT code accounts for dose delivered to CR receptors due to radiation shine from various locations. The RRCAT code input is developed following RG 1.183 [6] as applicable to determine the 30-day TEDE dose received by a CR receptor considering inhalation and submersion dose as well as gamma radiation shine from airborne radionuclides external to the CR, built up on filtration equipment, and held in a compartment before release to the environment. This is the dose consequence required to demonstrate compliance with Principal Design Criterion (PDC) 19 in NATD-LIC-RPRT-0002 Rev. 1, *Principal Design Criteria for the Natrium Advanced Reactor* [9] limits.

While the LBE EM described in this work was developed to determine radiological consequences that are required for the safety analysis report, only slight modifications are required to determine the dose results needed for the determination of the size of the PEP EPZ. The dose results required for this evaluation are described in the Natrium PEP EPZ Sizing Methodology as:

1. The mean and 95^{th} percentile TEDE dose delivered to a receptor at the PEP EPZ boundary over the 4-day period following the release of radionuclides to the environment.

2. The 24-hour red bone marrow acute dose delivered to a receptor at the PEP EPZ boundary and various distances beyond.

The modifications to the LBE EM required to determine these dose results are described in the Appendix. Note that the first consequence listed above will be determined for both LBE and DBA source terms. This is acceptable because the LBE EM may be applied to determine the consequences of any given radiological source term provided all input information listed in Section 3.3 for this EM is available.

2 INTRODUCTION

This ToR describes the EMs used to assess radiological consequences from the Natrium SFR power plant. The radiological consequences of LBEs as defined in NEI report 18-04 [5], endorsed by the NRC in 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* [10], as well as other events are determined with the three separate EMs described here. The criteria used to determine the acceptability of radiological consequences are also presented.

In NEI 18-04, LBEs are defined as, "… event sequences considered in the design and licensing basis of the plant …" with four event types: AOO, DBE, BDBE, and DBA. The first three LBE types are determined by the frequency of the event sequence whereas a DBA is derived from a DBE by prescriptively assuming that only safety-related (SR) systems, structures, and components (SSCs) are available to mitigate dose consequences. In this ToR, DBAs, which have no associated frequency due to prescriptive analysis assumptions, are referred to explicitly while the term LBEs is used to refer to the first three event types, AOO, DBE, and BDBE, as well as other quantified events (OQEs). The term OQE is not defined in NEI 18-04 and refers to event sequences with a frequency below the lower threshold defining a BDBE.

2.1 Objective and Scope

The process for selecting and evaluating LBEs is described as a series of tasks in NEI 18-04 [5]. This ToR describes the EM for determining radiological consequences of LBEs that is used in part to perform Tasks 7a and 7b in Figure 3-2 of NEI 18-04. The LBE EM and associated acceptance criteria are described in Section 3. The EM for dose consequences of DBAs that may be used in part to perform NEI 18-04 Task 7d as well as the associated acceptance criteria are described in Section 4. The EM for dose consequences related to CRH, required by PDC 19 [9], as well as the associated acceptance criteria are described in Section 5. The objective of the LBE EM is to apply a probabilistic approach with quantification of uncertainties whereas the objective of the DBA and CRH EMs is to apply a deterministic approach using conservative assumptions. The regulatory requirements and guidance, inputs, computational models, and evaluation methodology are described separately for each EM. The modifications to the LBE EM required to determine the dose results required for the determination of the size of the PEP EPZ as described in the Natrium PEP EPZ Sizing Methodology [2] are described in the Appendix. Only the determination of consequences from radiological source terms is within the scope of this ToR. The generation of source terms representative of LBEs or DBAs for the Natrium power plant are described in the Radiological Source Term Methodology Report [1] and are outside the scope of this work.

3 LICENSING BASIS EVENT EVALUATION MODEL

3.1 Objective and Scope

The objective of the LBE EM is to determine, through a probabilistic approach, the radiological consequences of an LBE for which a representative source term [1] has been determined. The radiological source term treated in this EM defines the airborne radionuclides released from the Natrium power plant to the environment as the result of an LBE. Following the release of airborne radionuclides to the environment, this EM considers the transport of radionuclide plume segments through the atmosphere and determines the resultant consequences of exposure to the released radionuclides. Atmospheric dispersion is a complex process that is affected by several phenomena including but not limited to wind speed and direction, atmospheric turbulence, building wakes, plume meander, and plume buoyancy. Besides atmospheric effects, the concentration of radionuclides in the plume decreases due to deposition of radionuclides onto the ground in both wet and dry weather conditions and radioactive decay. The concentration of some radionuclides in the plume increases due to the decay of parent radionuclides and resuspension of deposited radionuclides. These phenomena are considered to determine the radionuclide concentrations that receptors are exposed to following the initiation of the LBE. The following radiological consequences are then determined:

1. The TEDE dose received by a receptor on the EAB considering the dose due to inhalation of airborne radionuclides, radiation shine from airborne radionuclides, and radiation shine from radionuclides deposited on the ground. This quantity is determined at the 5th and 95th percentile as well as the mean value.
2. The probability of exceeding 100 mrem TEDE as defined above at the site boundary.
3. The average individual risk of early fatality within 1 mile of the EAB.
4. The average individual risk of latent cancer fatalities within 10 miles of the EAB.

The consequences described in Items 1, 2, and 3 are determined for a 30-day exposure period. The consequence described in Item 4 is determined for a 51-year exposure period in addition to the initial 30-day period. This initial 30-day period is referred to as the early phase and the following 51-year period is referred to as the chronic phase in this work.

3.2 Regulatory Requirements and Guidance

This EM may be used to determine radiological consequences as required by NEI 18-04 [5] LBE selection and evaluation Tasks 7a and 7b. The former of which, Evaluate LBEs Against F-C Target, requires that the mean, 5th, and 95th percentile 30-day TEDE dose to a receptor at the EAB be evaluated against frequency-consequence criteria termed the F-C Target in that report. The F-C Target is a vehicle for determining the risk significance of LBEs by comparing the dose resulting from an LBE against a limit that is scaled with consideration for the frequency of the LBE. As such, the F-C Target does not represent acceptance criteria for the dose consequences of a given LBE. Task 7b, Evaluate Integrated Plant Risk against QHOs and 10 CFR 20, requires that the following risk metrics be determined considering all LBEs cumulatively:

1. The probability of exceeding 100 mrem TEDE at the site boundary per plant-year.
2. The average individual risk of early fatality within 1 mile of the EAB per plant-year.
3. The average individual risk of latent cancer fatalities within 10 miles of the EAB per plant-year.

These three QHOs are determined by summing the product of the probability or risk determined via this EM (Items 2, 3, and 4 in Section 3.1) for a given LBE and the frequency of the LBE for all LBEs considered for the Natrium power plant. Because these are quantities integrated over all LBEs, they also do not represent acceptance criteria for the radiological consequences of a given LBE. The generation of the F-C Target and QHOs is outside the scope of this report. Only the determination of the radiological consequences required to generate those quantities is considered in this EM.

3.3 Evaluation Model Inputs

This EM is limited to the determination of the radiological consequences listed in Section 3.1 from a source term. As such, several items, including the determination of the radiological source term, are outside the scope of this report. Items that are used in this EM but developed separately are listed in Table 3-1. Note that the radiological source term analyzed is comprised of several individual inputs to this EM, all of which are listed.

Table 3-1: Listing of Licensing Basis Event Evaluation Model Inputs

Input Number	Description
3.1	The time-dependent, nuclide-specific release of airborne radionuclides to the environment, referred to in this work as the release matrix, from a given location within the Natrium power plant. If an LBE results in releases from several locations, all release-specific inputs in this table must be provided for all locations. This input is release specific.
3.2	The total inventory of all radionuclides considered in each release matrix available at the beginning of the event sequence. This input is release specific.
3.3	The element-specific aerosol particle size distribution of all radionuclides considered in each release matrix input to this EM. This input is release specific.
3.4	The time-dependent rate of release of the sensible heat of the plume containing airborne radionuclides for each release matrix input to this EM. This quantity is release specific but not nuclide specific.
3.5	The physical description of the building or building complex from which radionuclides are released to the environment including the height, length, width, and angle of the building or building complex relative to north. This input is release specific, but multiple releases may be specified for the same building in a given radiological source term.
3.6	The location within the building or building complex considered from which radionuclides are released to the environment. This input is release specific.
3.7	Meteorological data including wind speed and direction, stability category, rain rate, and mixing height that is representative of weather conditions at the Natrium power plant over the most limiting year (365 days).
3.8	The distribution of the population surrounding the Natrium power plant describing at least the area within 10 miles of the EAB.

3.4 Computational Model

The determination of radiological consequences is performed using WinMACCS version 4.1.0 as described in the SAND2021-11535, *MACCS Theory Manual* [11], SAND2022-7112, *MACCS (MELCOR Accident Consequence Code System) User Guide – Version 4.0, Revision 1* [12], and the MACCS user guide supplement [3]. As discussed in Section 6.1, WinMACCS version 4.2, *MACCS User Guide – Version 4.2* [13], is also acceptable for use in this EM. WinMACCS is a Windows-based interface and framework for performing consequence analysis. MACCS is used for calculating health and economic consequences from a release of radioactive materials into the atmosphere. For simplicity, the combined functions of MACCS and WinMACCS are referred to as MACCS in this work. MACCS was developed by Sandia National Laboratories for the NRC and has a diverse user base including the NRC, the U.S. Department of Energy (DOE), various research organizations, nuclear power plant applicants and licensees, as well as international regulators and technical support organizations.

The MACCS code input utilized for modeling the Natrium SFR generally follows the NRC sample MACCS model provided with the MACCS code identified as the Point Estimate LNT model. The NRC LNT model highlights NRC current practices, as considered in the SOARCA Report [4]. Adaptation of site modeling used in the SOARCA analysis is considered representative of the Natrium LBE radiological consequences. The main categories of MACCS model choices and parameters are GENERAL, ATMOS, EARLY, CHRONC, DOSE COEFFICIENTS, and COMIDA2. Because this EM only considers the submersion, inhalation, and ground shine exposure pathways, the MACCS computational module COMIDA2 (the food model option for ingestion exposure) is not utilized. Because no dose conversion factors (DCFs) are modified from the values in the data file used in this EM, the DOSE COEFFICIENTS (the option to modify values in the DCF file) MACCS computational module is also not utilized.

The following sections document how the MACCS code is used to determine the radiological consequences of an LBE source term. First, the adaption of the first two inputs in Table 3-1 to the input format of the MACCS code is described in Section 3.5. Then the other MACCS input selections that define the computational model utilized in this EM are developed from the remaining inputs in Table 3-1, the NRC LNT example, and SOARCA guidance in Section 3.6. Finally, the methodology for handling uncertain parameters is described in Section 3.7. Throughout, discussion of the MACCS code considers only one release matrix input to this EM. If multiple releases are specified, multiple executions of MACCS are required and the LBE radiological consequences are computed as the sum of the consequences from each release.

3.5 Adaption of Release Matrix to MACCS

The release matrix, Table 3-1 Item 3.1, input to this EM is generated according to the Radiological Source Term Methodology Report [1]. The MACCS code requires the initial radionuclide inventory, equivalent to Table 3-1 Item 3.2, and release fractions derived from the release matrix. The release matrix input data is specified to the MACCS code as release fractions for each chemical group. Therefore, to couple the release matrix to the MACCS code while preserving the fidelity of the radionuclide release profile, each radionuclide is treated as its own chemical group. The approach to determine MACCS plume release timing and fractions from the release matrix is discussed in Sections 3.5.2 and 3.5.3, respectively.

Other considerations for coupling the release matrix to version 4.1.0 of the MACCS code include the limitation of 150 on the number of trackable radionuclides and the restriction of the radionuclide progeny daughtering chains to a length of five. The approach to identify insignificant, trailing radionuclide releases to the environment and truncate the release matrix is discussed in Section 3.5.1. Note that these approaches can be utilized regardless of what method is leveraged to generate the release matrix and whether version 4.1.0 or 4.2 of the MACCS code is used.

3.5.1 Isotope Sensitivity Method

The release matrix input to this EM may include an arbitrary number of radionuclides. To quantify the relative importance of modeling a given radionuclide to accurately determine dose due to inhalation of airborne radionuclides, radiation shine from the airborne radionuclides, and radiation shine from radionuclides deposited on the ground, the radionuclide dose sensitivity is defined for the i^{th} radionuclide as:

[[

]]$^{(a)(4)}$

To account for dose due to inhalation, cloud shine, and ground shine, the following DCFs are used, respectively:

- The product of the effective inhalation DCF from Table 2.1 in Federal Guidance Report (FGR) 11, *EPA-520/1-88-020, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion* [14], and the offsite breathing rate of 3.5E-4 m^3/sec recommended in RG 1.183 [6] for the calculation of dose consequences from a nuclear reactor accident.
- The effective air submersion DCF from Table III.1 in FGR 12, *EPA-402-R-93-081, External Exposure to Radionuclides in Air, Water, and Soil* [15].
- The effective shine from contaminated ground surface DCF from FGR 12 Table III.3.

[[

]]$^{(a)(4)}$

The radionuclides are first screened by selecting the radionuclides that [[ ]]$^{(a)(4)}$ for further evaluation. Next, Equation 3-1 is evaluated using [[ ]]$^{(a)(4)}$ as defined above. Then all radionuclides are ranked by the computed dose sensitivity. To account for the effects of radioactive decay and the buildup of progeny radionuclides, the process described above is repeated for several radionuclide inventories each representing the initial inventory after some period less than the 30-day event duration has elapsed. Note that repeating the process above requires that Equation 3-1 is evaluated for all radionuclides in each repetition. The ranking of radionuclides based on isotope sensitivity results is then averaged across all inventories considered. The number of top ranked radionuclides required to account for at least [[ ]]$^{(a)(4)}$ of the dose sensitivity is determined as the number of radionuclides in the sum of radionuclide dose sensitivities computed for each inventory starting with the top ranked and proceeding in descending order that results in a total not less than [[ ]]$^{(a)(4)}$ for each inventory. The lesser of this number and 150, the maximum number of trackable radionuclides in the MACCS code, is then the number of radionuclides considered in the remainder of this EM. All radionuclides besides the number of top ranked radionuclides considered are truncated from the release matrix and initial inventory.

After truncation, the initial radionuclide inventory is input into MACCS via the Radionuclides form which specifies the name, chemical group, and inventory of each of the radionuclides treated in the MACCS calculation. The names of the top ranked radionuclides correspond to those in the DCF file associated with the project, described in Section 3.6.1, and the inventory of each is input to this EM, Table 3-1 Item 3.2. To preserve the fidelity of the nuclide-specific release matrix, each radionuclide is treated as its own chemical group leading to a unique chemical group number for each. This results in the number of chemical groups matching the number of radionuclides in the initial inventory.

3.5.1.1 Pseudostable Radionuclides

Decay chains are automatically terminated when the decay product is a stable isotope. In some cases, it is desirable to terminate a decay chain with a decay product that is not stable. This is commonly done when the decay product has a very long half-life or contributes very little to the overall dose. Terminating a decay chain in this way is done by adding the radionuclide to the pseudostable isotope list input to MACCS.

A MACCS trial run without pseudostable nuclides specified is executed to determine which decay chains were incomplete and not acceptable to MACCS. Any nuclides that are identified as an intermediate decay product between two modeled nuclides should be added via the Radionuclides form described in Section 3.5.1 if there are less than 150 nuclides already modeled. The pseudostable nuclides needed to terminate decay chains identified by the MACCS trial run are then input to the MACCS code as pseudostable nuclides. Radionuclides cannot be input in both the initial inventory and pseudostable nuclide fields.

3.5.1.2 General Isotope Sensitivity Results

The methodology described in Sections 3.5.1 and 3.5.1.1 was applied to Natrium-specific core radionuclide inventories composed of nearly [[ ]](a)(4) isotopes to determine a set of important radionuclides applicable to any LBE source term that is representative of release from the Natrium reactor core. Additionally, isotopes described as important in two Sandia National Laboratories reports, SAND2021-11703, *Preliminary Radioisotope Screening for Off-site Consequence Assessment of Advanced Non-LWR Systems* [17] and SAND2022-12018, *Quantitative Assessment for Advanced Reactor Radioisotope Screening Utilizing a Heat Pipe Reactor Inventory* [18], concerning the screening of isotopes for technologies including SFRs were also reviewed for inclusion in this representative, important isotope set. This additional review was intended to capture isotopes that were found to be important in other SFR isotope sensitivity evaluations including activation products, (e.g., activated sodium and tritium). Together, this evaluation of the core inventory and additional review results in a set of isotopes that are sufficient to capture the radiological consequences from source terms determined for core damage events. If a source term is input to this EM that represents a significantly different core inventory or effective release fractions than the ones analyzed here, the methodology described in Sections 3.5.1 and 3.5.1.1 will be applied to the input source term to develop an applicable set of important isotopes.

[[

]](a)(4)

[[

]](a)(4)

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Table 3-2: SFR Core Damage Effective Release Fractions

[[			
			]](a)(4)

[[

]](a)(4)

[[

]](a)(4)

Table 3-3: Natrium Release Isotopes Selected for MACCS Calculations

Release Isotopes Selected for MACCS Calculations							
[[							
							]](a)(4)

Table 3-4: Natrium Pseudostable Radionuclides Selected for MACCS Calculations

Pseudostable Radionuclides Selected for MACCS Calculations							
[[							
							]](a)(4)

3.5.2 Adaptive Plume Algorithm

The adaptive plume mesh (APM) algorithm uses a novel approach to adaptively construct the plume release time intervals used to represent the time-dependent, nuclide-specific release matrix in the MACCS code. The goal is to [[

]](a)(4)

[[ ]](a)(4) This is a complex task because the release matrix may include a large number of timesteps discretizing the release of radionuclides to the environment while version 4.1.0 of the MACCS code can only model up to 500 plume segments. As a result, some consolidation in time of the values provided in the release matrix is required. [[

]](a)(4)

3.5.3 Release Fraction Computation

The MACCS code calculates the release to the environment using the radionuclide inventory and release fractions of that inventory. Because the MACCS code tracks the decay of the radionuclide inventory with consideration for progeny produced by radioactive decay, the determination of release fractions requires a full progeny calculation of the radionuclide inventory. The radionuclide inventory as a function of time is:

$$\vec{R}_{inv}(t) = e^{t\boldsymbol{\Lambda}}\vec{R}_{inv}(0), \tag{3-3}$$

where, $\vec{R}_{inv}(t)$ is the vector of radionuclide inventories at time t and $\boldsymbol{\Lambda}$ is the decay matrix containing terms for both rate of loss due to decay and the rate of gain due to the decay of parent radionuclides. The amount of a radionuclide released to the environment over the duration of a plume interval may be computed [[ ]](a)(4) using the interpolant of the release matrix [[ ]](a)(4). The release fractions for each radionuclide in a plume are then computed and input into the MACCS code by taking the ratio of the amount of that radionuclide released in the plume segment and the inventory of that radionuclide present at the beginning of the plume segment release calculated by evaluating Equation 3-3 at the start time of the segment considered.

3.6 MACCS Model Parameters

This section describes the MACCS input selections that define the computational model used to determine radiological consequences in this EM; however, selections for all possible inputs are not explicitly listed. Due to the applicability of the MACCS code to a range of applications, many possible input variables are available to the user and different combinations of input variables may be leveraged to determine radiological consequences. Only the inputs required to define an acceptable computational model are described here.

3.6.1 Data File Specifications

Two external data files are input to MACCS. The first is the meteorological data file input to this EM, Table 3-1 Item 3.7. A meteorological data file based on the Electric Power Research Institute (EPRI) 3002003129, *Advanced Nuclear Technology: Advanced Light Water Reactor Utility Requirements Document (URD)* [19] may be used if shown to be conservatively representative of the plant location considered, i.e., shown to result in more limiting radiological consequences than the Table 3-1 Item 3.7 data file when used in this EM. Characteristics of 91 U.S. reactor sites tabulated in NUREG/CR-2239, *Technical Guidance for Siting Criteria Development*, [20] were used to develop the URD site meteorological database. Atmospheric dispersion factors determined following guidance in RG 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants* [21] for the 0-2 hour averaging period resulting from use of this database are estimated to be greater than the values for 80 to 90% of U.S. operating sites. Therefore, this database conservatively represents the consequences of most potential sites.

The second data file is the DCF file which must include all DCF values required to calculate the radiological consequences listed in Section 3.1 for all radionuclides specified in the release matrix. These DCF values should be based upon those reported in FGR 11 [14], FGR 12 [15], and FGR 13, *EPA-402-R-99-001, Cancer Risk Coefficients for Environmental Exposure to Radionuclides* [22]. One acceptable file is the "FGR13GyEquiv_TEDE_v2.inp" file distributed with version 4.2 of the MACCS code. This file contains effective dose DCFs from FGRs 11 and 12 that are appropriate for determining TEDE dose, as well as organ-specific DCFs from FGR 13 which may be used for the computation of early fatality and latent cancer fatality risk consistent with the SOARCA project [4]. Note that this file is an extension of the "FGR13GyEquiv_RevA.inp" file described in SAND2019-13422R, *FGR 13 Dose Conversion Factor Files* [23] distributed with version 4.1.0 of the MACCS code, which includes the addition of FGR 11 and 12 effective dose DCFs.

3.6.2 Atmospheric Dispersion

The transport and dispersion of airborne radionuclides through the atmosphere is affected by several phenomena. These phenomena include weather, wind speed and direction, atmospheric turbulence, building wakes, plume meander, and plume buoyancy. During transport, airborne radionuclides are also deposited on the ground. The MACCS input selections made to define the computation models applied to capture these phenomena and justification for these selections is provided in this section.

The plume of radionuclides released to the environment is modeled as a Gaussian plume. This is a typical model applied to plume transport and is consistent with other modeling decisions discussed in this section. Plume meander is accounted for with the Ramsdell and Fosmire (RAF) model which was integrated into MACCS to increase the nearfield capabilities. These are described in more detail in SAND2021-6924, *Implementation of Additional Models into the MACCS Code for Nearfield Consequence Analysis* [24]. The RAF model accounts for both building wake effects and low wind speed plume meander. The NRC has endorsed this model for offsite dispersion out to distances of 1,200 meters (RG 1.249, *Use of ARCON Methodology for Calculation of Accident-Related Offsite Atmospheric Dispersion Factors* [25]). Given that the EAB is expected to be within this distance, the RAF model is selected. If the EAB is modeled at a distance exceeding 1,200 meters, this selection will be re-justified or changed. To model building wake effects, the exterior dimensions of the building or building complex from which radionuclides are released to the environment as well as the orientation of that structure relative to north are specified as input to this EM, Table 3-1 Item 3.5. Note that the selection of the RAF model requires that the release be modeled as a point source as recommended in the MACCS user guide [12]. The dispersion parameters specified for this model are described in Section 3.6.2.1.

The buoyancy flux is an important value that MACCS uses to calculate the plume liftoff, plume trajectory, and the final amount of plume rise. This quantity is specified to be modeled from the sensible heat release rate input to this EM, Table 3-1 Item 3.4. If a sensible heat release rate is not input to this EM, a constant value of [[ ]](a)(4) may be conservatively assumed. This value was determined by assuming [[

]](a)(4) The assumed low leakage rate and temperature difference used to compute this value yield a low sensible heat release rate which results in a conservatively low amount of plume rise.

3.6.2.1 Dispersion Parameters

Plume dispersion during downwind transport is modeled using a Gaussian plume model. The crosswind and vertical extent of plume segments is expressed in terms of the crosswind (σ_y) and vertical (σ_z) standard deviations of the normal concentration distributions that characterize a Gaussian plume. Dispersion parameters are supplied in the form of a lookup-table based on the selection of the plume meander model for nearfield evaluations and the recommendation in SAND2021-6924 [24] that the Eimutis and Konicek parameterization of the Pasquill-Gifford diffusion curves, implemented via lookup-table, be used. This is consistent with the NRC LNT example distributed with the MACCS code. The σ_y and σ_z values for various distances and stability classes in the Eimutis and Konicek dispersion lookup-table used in this EM are taken from the MACCS input file provided in Section D.1 of SAND2021-6924. Consistent with the NRC LNT example distributed with the MACCS code, long-range crosswind dispersion is modeled as a function of time.

3.6.2.2 Weather Sampling

Random samples of weather data taken from the meteorological data file specified in Section 3.6.1 are used to compute radiological consequences. Through many weather trials, probabilistic radiological consequences capturing the inherent uncertainty in the weather assumed in the 30-day period following the initiation of the LBE may be determined. How these weather trials are sampled is specified with several MACCS input selections as described in this section.

Internally, the MACCS code defines weather bins to represent rain conditions at different distance intervals downwind from the accident site together with 16 bins for initial conditions organized by stability class and wind speed. The total number of bins is equal to the number of rain distance intervals (NRNINT) times one plus the number of rain intensity breakpoints (NRINTN) plus 16 ($NRNINT \times (NRINTN + 1) + 16$). The following rain distances are used in this EM as recommended in NUREG-1150, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants* [26] and consistent with the NRC LNT example distributed with the MACCS code: 3.22 km, 5.63 km, 11.27 km, 20.92 km, and 32.19 km. The following rain intensity breakpoints are used in this EM also as recommended in NUREG-1150 and consistent with the NRC LNT example: 2 mm/hr, 4 mm/hr, and 6 mm/hr. From these values, the number of weather bins is calculated to be 36.

The number of weather sequences to be sampled from each weather bin is specified as nonuniform. This nonuniform bin sampling scheme allows the user to directly specify the number of weather sequences to sample from each weather bin. The number of samples to be taken from each bin is determined by a trial execution of the MACCS code resulting in the weather frequency for each bin being output. The number of samples to be taken from each of the 36 weather bins is then computed as the product of the weather frequency for that bin and the total number of weather sequences being sampled. These values will vary depending on the meteorological data file used in this EM.

After a weather sequence is sampled, additional MACCS inputs must be specified to determine the effect of the sequence on the plume. Wind shift, the physical phenomena of the plume direction changing after release due to changes in the direction of wind, is included in the computational model. Wind rotation, a numerical convenience for acquiring more information out of a set of results without significantly increasing the computational time, is not included.

3.6.3 Plume Deposition

As the plume of airborne radionuclides travels through the atmosphere, some radionuclides are deposited on the ground. The resultant radiation shine from the radionuclides deposited on the ground is accounted for when determining radiological consequences. Because noble gases do not form aerosols and are highly inert, they are assumed to remain suspended in the air without deposition. [[

]](a)(4) In dry conditions, deposition modeling is dependent on the deposition velocity, a radionuclide-specific value input depending on the size of the radionuclide aerosol, Table 3-1 Item 3.3. Deposition in wet conditions is only modeled intermittently according to the weather trial considered and is modeled identically for all non-noble gas radionuclides. [[

]](a)(4)

After deposition, radionuclides may become resuspended. This is modeled within the EARLY computational module of the MACCS code during the early phase with a resuspension coefficient and resuspension coefficient half-life. The concentration in the air due to resuspension is then computed as the product of the ground concentration, the resuspension coefficient, and a reduction factor determined from the time elapsed since deposition and the half-life as specified in Equation 3-27 in the MACCS user guide [12]. Consistent with the NRC LNT example MACCS model distributed with the MACCS code, the resuspension coefficient and resuspension coefficient half-life are specified as 1E-4 m^{-1} and 1.82E5 sec, respectively. These values are also recommended in Section 4.2.2 of NUREG/CR-7270, *Technical Bases for Consequence Analyses Using MACCS (MELCOR Accident Consequence Code System)* [27] and were used in NUREG-4551 Volume 2, Revision 1, Part 7, *Evaluation of Severe Accident Risks: Quantification of Major Input Parameters: MACCS Input* [28].

The effect of weathering on the concentration of radionuclides deposited on the ground, as well as resuspension, is modeled with coefficients and coefficient half-lives within the CHRONC computational module of the MACCS code during the chronic phase. Unlike the EARLY computational module, multiple coefficient and coefficient half-life pairs are specified to capture the effect of weathering on both the ground shine and resuspension inhalation exposure pathways. These inputs are used to compute weathering factors for the two exposure pathways as shown in Equations 3-44 and 3-45 of the MACCS user guide [12]. The two ground shine weathering coefficients are specified as 0.4 and 0.6 with corresponding half-lives of 4.7E7 sec and 1.58E9 sec, respectively. The three resuspension weathering coefficients are specified as 1E-5 m^{-1}, 7E-9 m^{-1}, and 1E-9 m^{-1} with corresponding half-lives of 8.56E5 sec, 2.99E7 sec, and 1E10 sec, respectively. These values are consistent with the NRC LNT example MACCS model distributed with the MACCS code as well as the recommendations in Sections 4.2.2 and 4.2.3 of NUREG/CR-7270 [27].

3.6.4 Plant Area

Several aspects of the area surrounding the plant are specified to MACCS including the population distribution, Table 3-1 Item 3.8. The land surrounding the plant may be assumed to be entirely inhabited by a population distributed uniformly beginning at the EAB and extending at least to the furthest distance at which consequences are determined if this distribution is shown to be conservatively representative of the plant location considered, i.e., shown to result in more limiting radiological consequences than the Table 3-1 Item 3.8 distribution when used in this EM. To avoid influencing radiological consequences with boundary conditions, the area modeled in the MACCS code must be larger than the area for which consequences are determined.

3.6.5 Protective Actions

Generally, no credit is taken for protective actions during the early phase to ensure a conservative determination of radiological consequences. Because the MACCS code provides the user several options to specify how to model protective actions, this broad modeling decision affects several input selections. These selections are:

- No credit taken for the ingestion of potassium iodide
- No general or keyhole evacuation model considered
- The dose after which people are relocated at the normal or hot spot relocation times specified as an unphysically high value such as 1E10 Sv to ensure that no relocation is modeled

Within the chronic phase, credit is taken for protective actions when the dose from the ground shine and resuspension inhalation exposure pathways is projected to exceed limits specified to the MACCS code. The chronic phase is divided into two smaller phases with different projected dose limits. The first is a 1-year intermediate phase following the early phase wherein the projected effective dose limit is 2 rem per year. The second is a 50-year long-term phase following the intermediate phase wherein the projected effective dose limit is 0.5 rem per year. This specification of intermediate and long-term phase duration and projected dose limit is consistent with the NRC LNT example problem distributed with the MACCS code as well as the recommendations in Sections 4.4.1 and 4.4.2 of NUREG/CR-7270 [27] when an intermediate phase is modeled. The protective actions that may be credited when projected dose limits are exceeded include land decontamination, interdiction, and condemnation.

3.6.6 Dosimetry

The MACCS code offers numerous options for calculating radiological consequences of radionuclide releases and only the input parameters used to determine the consequences listed in Section 3.1 are described here. Consistent with the NRC LNT example MACCS model distributed with the MACCS code, cancer fatality risk is computed with the LNT model. Radiological consequences are modeled in the MACCS code in terms of organs of risk. These are organs for which DCFs are provided in the DCF data file prepended with either “A” to denote an acute dose or “L” to denote a lifetime dose. The organs of risk considered in this EM are listed in Table 3-5.

Table 3-5: Listing of Organs of Risk for MACCS Calculations

Organs of Risk			
[[			
			]](a)(4)

The average risk of individual early fatality is computed considering the acute (prepended with an "A") organs of risk from Table 3-5. The risk of early fatality is computed using the hazard function, given by Equation 3-35 of the MACCS user guide [12], which requires factors for each organ considered. The alpha and beta factors of the hazard function as well as the threshold dose below which the risk of fatality is zero given in the MACCS user guide are listed for all organs considered in this EM for early fatality in Table 3-6.

Table 3-6: Early Fatality Parameters for MACCS Calculations

Organ Name	Alpha Factor (Sv)	Beta Factor	Threshold (Gy)
[[			
			]](a)(4)

The average risk of individual latent cancer fatalities is computed considering the lifetime (prepended with a "L") organs of risk from Table 3-5 except for L-TEDE which is only used for TEDE dose calculations. The MACCS code is capable of computing latent cancer fatality risk with a linear-quadratic model. The quadratic portion of this model is disabled by specifying a linear factor of one, a quadratic factor of zero, and a dose limit for the linear-quadratic relationship of zero for all organs. The risk of latent cancer fatality is then computed from the fraction of the population that is susceptible to the latent cancer, the lifetime risk factor for a cancer fatality, and the dose and dose-rate effectiveness factor. The values for these parameters are taken from the NRC LNT example MACCS model distributed with the MACCS code and are listed in Table 3-7.

Table 3-7: Latent Cancer Fatality Parameters for MACCS Calculations

Organ Name	Fraction of Population Susceptible to Cancer	Lifetime Fatality Risk Factor (1/Sv)	Dose Effectiveness Factor
[[			
			]](a)(4)

3.6.7 Radiological Consequences

Two radiological consequence output options are used in this EM to determine the four radiological consequences listed in Section 3.1. These represent one set of MACCS outputs that are acceptable for determining radiological consequences. As noted in Section 3.6, the MACCS code includes many input options. This is especially true of the EARLY module output specification which includes several user options that can be leveraged in different ways to achieve equally valid results. Within the EARLY module, the calculation of doses in each grid element is specified to start with the arrival of the first plume segment at that location and continue for 30 days by setting the value of the MACCS parameter ENDEMP to 30 days.

The first output option specified is the peak dose. This output is calculated as the maximum average dose over a fine grid element for all fine grid elements within a radial interval. When the radial interval is centered on the EAB, this output is equivalent to the highest 30-day TEDE dose received by any receptor on the EAB. The target organ is specified as L-TEDE from Table 3-5 so that the TEDE dose is calculated for the whole body rather than a specific organ, the inner and outer radii of the radial interval are specified as centered on the EAB, and the complementary cumulative distribution function (CCDF) reporting option is selected. The 5th percentile TEDE dose value may be extracted from the CCDF which contains doses for a range of probabilities spanning from near zero to near one. The mean and 95th percentile TEDE dose values are reported directly by MACCS separately from the CCDF. If the site boundary is not coincident with the EAB, a second peak dose value must be specified identically to the first peak dose value but with a radial interval centered on the site boundary. The probability of exceeding 100 mrem at the site boundary may be deduced from the CCDF of this result or the first peak dose value if the EAB and site boundary are coincident.

The second output option specified is the population-weighted risk. This output is calculated as the number of cases of a health effect within a region and divided by the total population of that region. Two values are specified to be output. The first is the total early fatality health effect specified over a radial interval with an inner radius equal to or less than the EAB and an outer radius equal to or greater than the EAB plus one mile. The total early fatality health effect is the cumulative early fatality risk of each organ listed in Table 3-6 so this value is equivalent to the average individual risk of early fatality within one mile of the EAB. The second output value is the total cancer fatality health effect specified over a radial interval from an inner radius equal to or less than the EAB to an outer radius greater than or equal to the EAB plus 10 miles. The total cancer fatality health effect is the cumulative latent cancer fatality risk of each organ listed in Table 3-7 so this value is equivalent to the average individual risk of latent cancer fatalities within 10 miles of the EAB.

3.7 MACCS Analysis Uncertainty Methodology

While applicable values for a number of MACCS parameters or acceptable methods to determine these values were presented in Sections 3.5 and 3.6, robust justification for some MACCS inputs may not be available. Additionally, values input to this EM, Table 3-1, may have associated uncertainties. This section presents an acceptable methodology for determining the sensitivity of radiological consequences to these values as well as an acceptable treatment of the uncertainty of these values.

3.7.1 Parameter Sensitivity

An analysis is performed to determine the sensitivity of radiological consequences to parameters with some associated uncertainty. One acceptable method to perform this analysis is direct manipulation of parameters of interest. Nominal values for all required parameters are input into the MACCS code so that it may be executed, and radiological consequences may be computed. See Section 3.6.7 for detail on the code outputs that constitute radiological consequences. Then, a parameter of interest is repeatedly perturbed to different values within the range of the uncertainty surrounding the nominal value of that parameter and MACCS is repeatedly executed. The resulting radiological consequences may then be studied as a function of the perturbed parameter and the sensitivity of consequences to the parameter may be determined.

Both peak dose and population-weighted risk MACCS outputs should be considered when determining parameter sensitivity as only one of these output types may be sensitive to the studied parameter. If radiological consequences are found to be relatively insensitive to the parameter, (i.e., variation of the parameter does not significantly affect either peak dose or population-weighted risk MACCS outputs), a single nominal value may be assumed when determining the final radiological consequences produced by application of this EM. If the parameter does significantly affect either radiological consequence output, the treatment described in Section 3.7.2 is applied.

3.7.2 Uncertain Parameter Treatment

For uncertain parameters that contribute significantly to radiological consequences, two acceptable approaches are described. First, although it should be avoided if possible as the objective of this EM is to provide a probabilistic radiological consequence assessment, values that conservatively bound the uncertainty surrounding parameters may be prescribed. This approach may require multiple executions with the parameter value selected separately for each consequence if the parameter affects peak dose and population-weighted risk MACCS outputs differently. Generally, the second approach should be pursued.

The second acceptable treatment of uncertain parameters is randomly sampling values for uncertain inputs from a probability distribution. Note that one acceptable source of probability distributions for many parameters input to the MACCS code is NUREG/CR-7270 [27]. Many parameters may be sampled using Monte Carlo techniques to generate the inputs for a single MACCS execution. The values of uncertain inputs are repeatedly sampled and MACCS is repeatedly executed to generate many radiological consequence samples. [[

]](a)(4) Care should be taken when extracting final results from the sampled set because a single MACCS execution outputs 5th percentile, mean, and 95th percentile results due to the weather sequence random sampling described in Section 3.6.2.2. [[

]](a)(4) Additionally, the MACCS code includes post-processing capabilities that may be utilized to determine the mean, 5th and, 95th percentile results of the sampled set. These QHO and dose results represent the final determination of this EM.

The treatment of uncertainty with regards to the source term input, Table 3-1 Item 3.1, will be expected to follow one of the above methods depending on the treatment of uncertainty utilized in the development of the source term [1]. If the treatment of uncertainty in the development of the source term input requires a different approach from the two described above, it will be described and justified at the time of application.

4 DESIGN BASIS ACCIDENT EVALUATION MODEL

4.1 Objective and Scope

The objective of the DBA EM is to determine, through a conservative, deterministic approach, the dose consequences of a DBA for which a representative source term has been determined. The source terms analyzed in this EM are derived from the DBEs analyzed by the LBE EM described in Section 3 by only taking credit for SR SSCs to mitigate dose consequences. Explicit treatment of atmospheric transport from the point of release of radionuclides to receptor locations is not considered in this EM. Instead, atmospheric dispersion factors are determined externally and input to this EM. These factors allow the direct computation of radionuclide concentrations in the environment that receptors are exposed to over a 30-day period. The following dose consequences are then determined:

1. The highest TEDE dose received over any 2-hour period by a receptor on the EAB considering the dose due to inhalation of and radiation shine from airborne radionuclides, referred to in this work as inhalation and submersion dose.

2. The 30-day TEDE dose received by a receptor on the outer boundary of the LPZ also considering inhalation and submersion dose.

4.2 Regulatory Requirements and Guidance

This EM may be used to determine dose consequences as required by NEI 18-04 [5] LBE selection and evaluation Task 7d. The NEI 18-04 task, Perform Deterministic Safety Analyses Against 10 CFR 50.34, states that the dose consequences of DBAs are determined using conservative assumptions and compared with 10 CFR 50.34 [7] dose criteria. The criteria from 10 CFR 50.34 that are applicable to this EM are as follows:

1. Per 10 CFR 50.34(a)(1)(ii)(D)(1), “An individual located at any point on the boundary of the exclusion area for any 2-hour period following the onset of the postulated fission product release, would not receive a radiation dose in excess of 25 rem total effective dose equivalent (TEDE).” This criterion is equivalent to limiting the dose consequence described in Section 4.1 Item 1 to 25 rem.

2. Per 10 CFR 50.34(a)(1)(ii)(D)(2), “An individual located at any point on the outer boundary of the low population zone, who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a radiation dose in excess of 25 rem total effective dose equivalent (TEDE).” This criterion is equivalent to limiting the dose consequence described in Section 4.1 Item 2 to 25 rem.

These limits are applicable to each DBA for which dose consequences are determined with this EM and as such, constitute the acceptance criteria for the dose consequences of a DBA.

The dose consequences calculated for DBAs in this EM align with traditional deterministic safety analyses of DBAs typically performed by license applications not following NEI 18-04 guidance. Because of this, there are several regulatory guides that, while not directly applicable to the Natrium SFR technology, inform acceptable approaches to determining dose results. Throughout this EM, the guidance of RG 1.183 [6] is used as applicable.

4.3 Evaluation Model Inputs

This EM is limited to the determination of dose consequences listed in Section 4.1 from a source term. As such, several items, including the determination of the radiological source term and atmospheric dispersion factors, are outside the scope of this report. Items that are used in this EM but developed separately are listed in Table 4-1.

Table 4-1: Listing of Design Basis Accident Evaluation Model Inputs

Input Number	Description
4.1	The time-dependent, nuclide-specific release of airborne radionuclides to the environment, referred to in this work as the release matrix, from a given location within the Natrium power plant. If a DBA results in releases from several locations, all release specific inputs in this table must be provided for all locations. This input is release specific.
4.2	Atmospheric dispersion factors (χ/Q factors) corresponding to the location of the release and the most limiting location on the EAB. The 0-2 hour averaging period factor must be included. This input is release specific.
4.3	χ/Q factors corresponding to the location of the release and the most limiting location on the outer boundary of the LPZ. The 0-2, 2-8, 8-24, 24-96, and 96-720 hour averaging period factors must be included. This input is release specific.

4.4 Computational Model

With the release matrix and χ/Q factors for the EAB and LPZ locations, Table 4-1 Items 4.1, 4.2, and 4.3, the inhalation and submersion doses delivered to receptors on the EAB or boundary of the LPZ may be computed directly using Equations 7 and 8 from RG 1.195, *Methods and Assumptions for Evaluating Radiological Consequences of Design Basis Accidents at Light-Water Nuclear Power Reactors* [30] and DCFs consistent with the dose quantity computed. This calculation may be performed by the SNAP/RADTRAD code version 4.0 [8], referred to as RADTRAD in this work, which is maintained as part of the NRC sponsored Radiation Protection Computer Code Analysis and Maintenance Program. The RADTRAD code was developed for the NRC to assess the dose delivered to receptors at the EAB, LPZ, and in the CR for various DBAs starting from the release of radionuclides in some compartment of the plant being analyzed.

The implementation of the RADTRAD code is explained in detail in NUREG/CR-7220, SNAP/RADTRAD 4.0: *Description of Models and Methods*. The RADTRAD code first computes the radionuclide release to the environment at a given timestep by modeling several complex physical phenomena to account for transport of radionuclides from the release location within some plant compartment to the environment. The dose delivered to offsite (EAB and LPZ) receptors is then computed directly as the product of the integrated radionuclide release, the χ/Q factor, the DCF consistent with the dose quantity computed, and, only for the inhalation dose, the receptor breathing rate as specified in Equations 4-45 and 4-47 in NUREG/CR-7220.

The RADTRAD code is not used in this EM because the release matrix is input, Table 4-1 Item 4.1, not calculated. The release matrix may contain many radionuclides released over many timesteps. As a result, it is not possible to input these releases into the RADTRAD code without significant loss of resolution in either the number of radionuclides tracked or the time dependence of the release. For this reason, the RRCAT code version 1.0, which can compute offsite receptor inhalation and submersion doses equivalently to the algorithm used in RADTRAD described above, was developed. Following the guidance in RG 1.183 [6], the RRCAT code is input with effective dose equivalent DCFs from FGR 12 Table III.1 [15] to compute submersion dose and committed effective dose equivalent DCFs from FGR 11 Table 2.1 [14] to compute inhalation dose. For consistency with the application of FGR 12 DCFs, half-life and decay progeny information input to RRCAT is taken from FGR 12 Table A.1.

4.5 Atmospheric Dispersion

To calculate dose consequences for any receptor, χ/Q factors must be specified for the location of the receptor. For the LPZ receptor, a set of χ/Q factors are input corresponding to averaging periods of 0-2, 2-8, 8-24, 24-96, and 96-720 hours. In accordance with RG 1.183 [6] guidance and to ensure that the most limiting release in the release matrix corresponds to the most limiting χ/Q factors, the 0-2 hour χ/Q factor is applied to the 2-hour period in which the limiting release to the environment occurs. The period of limiting release to the environment, referred to in this work as the limiting release period, is defined in this EM as the release period that results in the highest 2-hour TEDE dose to the receptor at the EAB. This period is determined by a trial execution of the RRCAT code wherein only the EAB receptor is specified with a constant χ/Q factor of the 0-2 hour averaging period, Table 4-1 Item 4.2, and a constant breathing rate of 3.5E-4 m^3/sec for the duration of the accident.

For the LPZ receptor, χ/Q factors are structured around this limiting release period consistent with RG 1.183 [6] guidance. First the 0-2 hour χ/Q factor is applied to the limiting release period. Next, the 2-8-hour factor is applied for half of the duration of the factor (three hours) before the limiting release period and half after. If the beginning of the accident is reached before the factor can be applied to the duration preceding the limiting release period, the remainder of the duration of the factor should be applied after the limiting release period. This process is repeated for the remaining χ/Q factors to define the entire 30-day accident duration.

4.6 Offsite Dose Consequences

To compute dose consequences for the receptor at the EAB, the 0-2 hour averaging period χ/Q factor, Table 4-1 Item 4.2, and a breathing rate of 3.5E-4 m^3/sec, the most limiting breathing rate recommended for offsite dose analyses in RG 1.183 [6], are specified. Note that these specifications are identical to those used in the trial RRCAT execution used to determine the limiting period of release described in Section 4.5. To compute dose consequences for the receptor on the outer boundary of the LPZ, the LPZ χ/Q factors, Table 4-1 Item 4.3, structured following the methodology presented in Section 4.5, are specified. In addition, breathing rates of 3.5E-4 m^3/sec, 1.8E-4 m^3/sec, and 2.3E-4 m^3/sec corresponding to the first 8 hours, the following 16 hours, and the remainder of the accident duration are specified as recommended in RG 1.183 [6]. These specifications as well as the release matrix, Table 4-1 Item 4.1, are then input into the RRCAT code which may then be executed to determine dose consequences 1 and 2 from Section 4.1.

5 CONTROL ROOM HABITABILITY EVALUATION MODEL

5.1 Objective and Scope

The objective of the CRH EM is to determine, through a conservative, deterministic approach, the dose consequences required to demonstrate habitability in the CR. The source terms analyzed in this EM include DBEs, a subset of LBEs, as well as the major accident source term. The development of these source terms [1] and identification of the major accident source term are outside the scope of this EM. Only the methodology applied to determine the dose consequences of these inputs is described. Similar to the DBA EM described in Section 4, atmospheric transport is accounted for using atmospheric dispersion factors. Several phenomena in addition to atmospheric transport are considered in this EM to determine dose delivered to receptors in the CR during the event duration. These include the flow of radionuclides into the CR considering both air flow and filtration, the change in radionuclide concentration in the CR due to radioactive decay and production of progeny radionuclides and shine dose from several sources. Considering these phenomena, the 30-day TEDE dose received by a CR receptor considering inhalation and submersion dose as well as gamma radiation shine from airborne radionuclides external to the CR, built up on filtration equipment, and held in a compartment before release to the environment, is determined.

5.2 Regulatory Requirements and Guidance

The CRH EM is used to determine dose consequences as required by PDC-19 [9]. The language of PDC-19 relating to CR radiological habitability is, “Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem total effective dose equivalent, as defined in § 50.2 for the duration of the accident.” This criterion is equivalent to limiting the dose consequence described in Section 5.1 to 5 rem. This limit is applicable to each source term for which dose consequences are determined with this EM and as such, constitutes acceptance criterion for CRH. Throughout this EM, the guidance of RG 1.183 [6] is used as applicable.

5.3 Evaluation Model Inputs

This EM is limited to the determination of the dose consequence described in Section 5.1 from a source term. As such, several items, including the determination of the radiological source term and atmospheric dispersion factors, are outside the scope of this report. Items that are used in this EM but developed separately are listed in Table 5-1. Note that the radiological source term analyzed is comprised of several individual inputs to this EM, all of which are listed.

Table 5-1: Listing of Control Room Habitability Evaluation Model Inputs

Input Number	Description
5.1	The time-dependent, nuclide-specific release of airborne radionuclides to the environment, referred to in this work as the release matrix, from a given location within the Natrium power plant. If an event results in releases from several locations, all release-specific inputs in this table must be provided for all locations. This input is release specific.
5.2	The specification of radionuclides in the release matrix as either entirely aerosols or entirely vapors. If both aerosols and vapors are released, two release matrices must be specified, each containing entirely aerosol or vapor release information. This input is release specific.
5.3	The physical description of the compartment from which radionuclides are released to the environment, referred to in this work as the final compartment, including the dimensions, the regions occupied by equipment, and the orientation of the compartment relative to the CR. This input is release specific, but multiple releases may be specified for the same compartment in a given radiological source term.
5.4	The time-dependent leakage rate from the final compartment to the environment. This input is release specific.
5.5	$\chi/_Q$ factors corresponding to the location of the release and the air intake location of the CR. If there are multiple air intake locations, factors must be provided for each. The 0-2, 2-8, 8-24, 24-96, and 96-720-hour averaging period factors must be included. This input is release specific.
5.6	The physical description of the CR including the dimensions and the regions occupied by equipment.
5.7	The description of the CR heating, ventilation, and air conditioning system including all air flow paths and in-leakage from the environment and all filtration equipment.

5.4 Computational Model

With the release matrix and $\chi/_Q$ factors for the CR air intake location, Table 5-1 Items 5.1 and 5.5, the inhalation and submersion doses delivered to a receptor standing outside the CR may be computed as described in the DBA EM in Section 4. However, more effort is required to compute the inhalation and submersion doses delivered to receptors inside the CR because the time dependent radionuclide concentration in the CR must be determined considering air flow rates, filtration equipment, radioactive decay, and the production of progeny radionuclides. This calculation is performed by the RRCAT code which implements equivalent mathematical models to the RADTRAD code for the calculation of CR dose consequences.

As described in Section 4.4, the RADTRAD code models several complex phenomena to determine the radionuclide release to the environment, which is an input to this EM, Table 5-1 Item 5.1. Next, the RADTRAD code relates the release to the environment to the concentration outside the CR using χ/Q factors. Then, two matrix equations are solved to compute the radionuclide concentration in the CR. The first is the transport equation, Equation 4-6 in NUREG/CR-7220 [8], which considers the removal of radionuclides due to exhaust to the environment or the filtration of air being recirculated as well as the gain of radionuclides due to all, possibly filtered, air flowing into the CR from the environment. The second is the decay equation, Equation 4-10 in NUREG/CR-7220, which considers the removal of radionuclides due to radioactive decay and gain of radionuclides produced by the decay of parent radionuclides. These two equations are solved alternatively by numerically evaluating the analytical matrix exponential solutions. Using this algorithm to compute CR radionuclide concentrations, the inhalation and submersion doses delivered to CR receptors are computed as the product of the integrated radionuclide concentration in the CR, the DCF, the occupancy factor, and either the breathing rate for inhalation dose or the inverse of the Murphy-Campe geometric factor (Murphy, K.G. and Campe, K.M., *Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19, 13th AEC Air Cleaning Conference* [31], for the submersion dose as specified in Equations 4-48 and 4-50 in NUREG/CR-7220.

Consistent with the DBA EM, the RADTRAD code is not used in this EM because the release matrix input, Table 5-1 Item 5.1, is incompatible with it. Instead, the RRCAT code, which can compute CR receptor inhalation and submersion doses equivalently to the algorithm used in RADTRAD described above, is used. The algorithm implemented is identical to the one described for RADTRAD with minor exceptions including that the transport and decay equations formed and solved separately in RADTRAD are instead formed and solved as one equation which considers the same phenomena. Following the guidance in RG 1.183 [6], the RRCAT code is input with effective dose equivalent DCFs from FGR 12 Table III.1 [15] to compute submersion dose and committed effective dose equivalent DCFs from FGR 11 Table 2.1 [14] to compute inhalation dose. For consistency with the application of FGR 12 DCFs, half-life and decay progeny information input to RRCAT is taken from FGR 12 Table A.1.

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A deficiency of the RRCAT code compared to the RADTRAD code is the limited handling of the chemical form of released radionuclides. The RADTRAD code allows users to specify filtration efficiencies for different chemical forms of airborne radionuclides. The chemical forms of the radionuclides are then tracked, and the corresponding filtration efficiency is applied when evaluating the transport equation. The RRCAT code does not track the chemical forms of radionuclides. As a result, if radionuclides are released in both aerosol and vapor form, two release matrices, each containing only the releases of one form, are required as specified in Table 5-1 Item 5.2. The code is then executed twice, once with each release matrix and corresponding filtration efficiencies input. Note that consistent with RADTRAD, noble gases are conservatively assumed to not be filtered. An additional deficiency of the RRCAT code is that only one set of $\chi/_Q$ factors are allowed to be specified for the CR air intake location. If there are CR air intake locations sufficiently separated such that different $\chi/_Q$ factors are specified for each location, multiple RRCAT executions are again required. One execution per air intake location is needed. Finally, the RRCAT code only computes dose consequences for a single release matrix at a time. If multiple release matrices are specified, multiple RRCAT executions are again required. The following sections document how the RRCAT code is leveraged to determine the dose consequences for a source term. Throughout, discussion of the RRCAT code considers only one set of CR $\chi/_Q$ factors and one release matrix containing a single chemical form. If this is not the case, multiple executions of RRCAT are required and the dose consequences are computed as the sum of independent dose results. [[

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5.5 Shine Dose

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5.6 Control Room Dose Consequences

To compute the dose consequences for the CR receptor, the limiting release period is determined with a trial execution of RRCAT as described in Section 4.5 with some constant χ/Q factor in place of the EAB 0-2 hour χ/Q factor. The CR χ/Q factors, Table 5-1 Item 5.5, are then structured following the methodology described for the LPZ receptor Section 4.5. A constant breathing rate of 3.5E-4 m^3/sec, as recommended by RG 1.183 [6], is also specified. Additionally, the free volume of the CR, deduced from Table 5-1 Item 5.6, is specified as well as occupancy factors of 1, 0.6, and 0.4 corresponding to the first 24 hours, the following 72 hours, and the remainder of the accident duration as recommended in RG 1.183 [6]. Finally, the air flow paths into, out of, or recirculating within the CR, Table 5-1 Item 5.7, are specified as well as the efficiency with which radionuclides are filtered from the air flow path. Filtration efficiencies are determined from the description of the filtration equipment associated with the air flow path, Table 5-1 Item 5.7, and the chemical form of the release matrix, Table 5-1 Item 5.2. These specifications as well as the release matrix, Table 5-1 Item 5.1, [[ ]](a)(4) are then input into the RRCAT code which may then be executed to determine the dose consequence described in Section 5.1.

5.7 Uncertainty Treatment

This EM is applied to DBE and the major accident source terms to demonstrate CRH. Given that the Natrium CR is classified as non-safety-related with special treatment, SSCs with the same classification may be credited to mitigate dose consequences in this EM. Uncertainty related to the behavior of these SSCs, and other EM inputs, is accounted for with bounding conservative assumptions consistent with the intent of this EM to provide a deterministic dose assessment; however, effort should be made to avoid the arbitrary “stacking” of conservative assumptions that lack physical meaning. Note that conservative assumptions made relating to non-safety-related with special treatment SSC operation should bound realistically expected behavior of the SSC not the availability of the SSC as it is credited in this EM.

6 CONCLUSIONS ON EVALUATION MODELS

The proposed EMs provide both probabilistic and deterministic methodologies for evaluating the radiological consequences of LBE and DBA source terms. The probabilistic LBE EM utilizes the MACCS code [3] following the NRC LNT example and SOARCA [4] guidance as applicable. This EM will be utilized to determine the radiological consequences of LBEs that are required to be evaluated by NEI 18-04 [5] LBE selection and evaluation Tasks 7a and 7b relating to the F-C Target and QHOs, respectively. The deterministic DBA EM utilizes the mathematical models of the RADTRAD code [8], implemented equivalently in the RRCAT code, and follows RG 1.183 [6] guidance as applicable to determine offsite dose consequences. The offsite dose consequences determined by the DBA EM may be used to demonstrate compliance with 10 CFR 50.34 [7] dose criteria in accordance with NEI 18-04 LBE selection and evaluation Task 7d. The deterministic CRH EM utilizes the RRCAT code and follows RG 1.183 [6] guidance as applicable and determines CR dose consequences. The CR dose consequences determined by the CRH EM may be used to demonstrate compliance with the radiological habitability requirements set forth in PDC-19 [9]. In the LBE and CRH EMs, a methodology to address uncertainty associated with model inputs or parameters which applies either a probabilistic or deterministic approach in accordance with the objective of the EM is proposed.

The LBE EM changes required to determine dose consequences to inform the sizing of the PEP EPZ as described in the Natrium PEP EPZ Sizing Methodology ToR [2] are described in the Appendix. The LBE EM may be applied to determine the consequences of any given radiological source term provided all input information listed for the EM is available. This allows the determination of dose consequences of DBA source terms using the modified LBE EM as required by the PEP EPZ sizing analysis.

6.1 Computational Model Updates

Several computer codes, MACCS, RRCAT, [[ ]](a)(4), implement aspects of the methodology described in this ToR. These codes are controlled in accordance with a quality assurance program which complies with 10 CFR 50 Appendix B [34], as engineering computer programs (ECPs). Corrections, changes, and improvements to these ECPs that do not fundamentally alter the modeling capabilities required for the radiological consequence EM in which they are used may be made without prior NRC review and approval. Some examples include changes in the numerical methods to improve efficiency, the addition or enhancement of features that support effective code input/output and automation, or the porting to a new computer platform. Changes which do alter the modeling capabilities required for a given radiological consequence EM and result in increased radiological consequences also may be made without NRC review and approval. Additionally, other computer codes which equivalently implement aspects of the methodology described in this ToR may be used in place of those listed provided they are also controlled by a quality assurance program.

7 REFERENCES

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8 APPENDIX - ADAPTATION OF LICENSING BASIS EVENT EVALUATION MODEL TO EMERGENCY PLANNING ZONE SIZING

The PEP EPZ sizing methodology for the Natrium power plant is described in a separate ToR [2] which describes the radiological consequence acceptance criteria for evaluating the EPZ sizing.

The methodology referred to in the PEP EPZ ToR is the licensing basis event EM described in Section 3 of this ToR. Only minor changes to the MACCS code inputs described in Section 3 are needed to produce the two dose consequences evaluated for PEP EPZ sizing: the mean and 95th percentile 4-day TEDE dose at the PEP EPZ boundary, and the 1-day red bone marrow acute dose results at the PEP EPZ boundary as well as various distances beyond. Note that the CHRONC module is not needed for evaluation of these dose consequences.

To output TEDE dose results at the PEP EPZ boundary as required by PEP EPZ sizing methodology, the evaluation duration is reduced from the 30 days considered in the LBE EM to 4 days. Then, the peak dose output option is used. As noted in Section 3.6.7 of this ToR, this output is calculated as the maximum average dose over a fine grid element for all fine grid elements within a radial interval. As such, when the target organ is specified as L-TEDE resulting in TEDE dose being calculated and the inner and outer radii of the radial interval are specified as centered on the PEP EPZ boundary, the resulting output is equivalent to the 4-day TEDE dose at the PEP EPZ boundary.

To output the acute red bone marrow dose results at several distances as required by PEP EPZ sizing methodology, the evaluation duration is reduced from the 30 days considered in the LBE EM to 1 day. Then, the peak dose output option is used again. When the peak dose target organ is specified as A-RED MARR, the 24-hour red bone marrow effective acute dose is computed. For the PEP EPZ boundary and all distances beyond it which are considered in the PEP EPZ sizing analysis, a peak dose value with a target organ of A-RED MARR, inner and outer radii values which are centered on the distance considered, and the CCDF reporting option selected is specified.

With the changes to the MACCS input made as described above, code execution results in the dose consequences required for the PEP EPZ sizing analysis. If uncertain input parameter sampling is used as described in Section 3.7.2 of this ToR, mean and 95th percentile results should be extracted as described for the 30-day TEDE dose in that section.

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