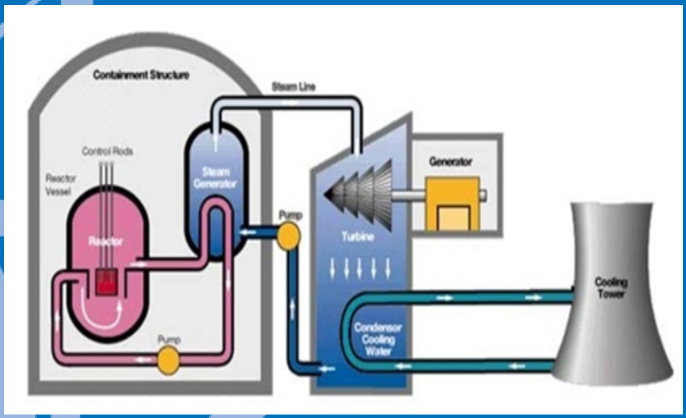
U.S. NRC Level 3 Probabilistic Risk Assessment (PRA) Project

Volume 3d: Reactor, At-Power, Level 3 PRA for Internal Events and Floods



April 2022

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) performed a full-scope site Level 3 probabilistic risk analysis (PRA) project (L3PRA project) for a two-unit pressurized-water reactor reference plant, responding to Commission direction in the staff requirements memorandum (SRM) (Agencywide Documents and Management System [ADAMS] Accession No. ML112640419) resulting from SECY-11-0089, "Options for Proceeding with Future Level 3 Probabilistic Risk Assessment (PRA) Activities" (ADAMS Accession No. ML11090A039).

As described in SECY-11-0089, the objectives of the L3PRA project are to:

- Develop a Level 3 PRA, generally based on current state-of-practice methods, tools, and data,[1] that (1) reflects technical advances since the last NRC-sponsored Level 3 PRAs (NUREG-1150[2]), which were completed over 30 years ago, and (2) addresses scope considerations that were not previously considered (e.g., low power and shutdown [LPSD] risk, multi-unit risk, other radiological sources).
- Extract new insights to enhance regulatory decision making and to help focus limited NRC resources on issues most directly related to the agency's mission to protect public health and safety.
- Enhance PRA staff capability and expertise and improve documentation practices to make PRA information more accessible, retrievable, and understandable.
- Demonstrate technical feasibility and evaluate the realistic cost of developing new Level 3 PRAs.

The scope of the L3PRA project encompasses all major radiological sources on the site (i.e., reactors, spent fuel pools, and dry cask storage), all internal and external hazards, and all modes of plant operation. Fresh nuclear fuel, radiological waste, and minor radiological sources (e.g., calibration devices) are not included as part of the scope. In addition, deliberate malevolent acts (e.g., terrorism and sabotage) are excluded from the scope of this study.

This report, one of a series of reports documenting the models and analyses supporting the L3PRA project, specifically addresses the reactor, at-power, Level 3 PRA model for internal events and internal floods for a single unit. The analyses documented herein are based

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[1] "State-of-practice" methods, tools, and data refer to those that are routinely used by the NRC and industry or have acceptance in the PRA technical community. While the L3PRA project is intended to be a state-of-practice study, note that there are several technical areas within the project scope that necessitated advancements in the state-of-practice (e.g., modeling of multi-unit site risk, modeling of spent fuel in pools or casks, and of human reliability analysis for other than internal events and internal fires).

[2] NUREG-1150, "Severe Accident Risk: An Assessment for Five U.S. Nuclear Power Plants," December 1990.

information for the reference plant as it was designed and operated as of 2012 and does not reflect the plant as it is currently designed, licensed, operated, or maintained.[3]

A full-scope site Level 3 PRA for a nuclear power plant site can provide valuable insights into the importance of various risk contributors by assessing accidents involving one or more reactor cores as well as other site radiological sources. Furthermore, some future advanced light water reactor (ALWR) and advanced non-light water reactor (NLWR) applicants may rely heavily on results of analyses similar to those used in the L3PRA project to establish their licensing basis and design basis by using the Licensing Modernization Project (LMP) (NEI 18-04, Rev. 1) which was recently endorsed via RG 1.233. Licensees who use the LMP framework are required to perform Level 3 PRA analyses. Therefore, another potential use of the methodology and insights generated from this study is to inform regulatory, policy, and technical issues pertaining to ALWRs and NLWRs.

CAUTION: While the L3PRA project is intended to be a state-of-practice study, due to limitations in time, resources, and plant information, some technical aspects of the study were subjected to simplifications or were not fully addressed. As such, inclusion of approaches in the L3PRA project documentation should <u>not</u> be viewed as an endorsement of these approaches for regulatory purposes.

[3] An overview report, which covers all three PRA levels, has been created for each major element of the L3PRA project scope (e.g., for the combined internal event and internal flood PRAs for a single reactor unit operating at full power). These overview reports include a reevaluation of plant risk based on a set of updated plant equipment and PRA model assumptions (e.g., incorporation of the current reactor coolant pump shutdown seal design at the reference plant and the potential impact of the U.S. nuclear power industry's proposed safety strategy, called Diverse and Flexible Mitigation Capability [FLEX], both of which reduce the risk to the public).

FOREWORD

The U.S. Nuclear Regulatory Commission (NRC) performed a full-scope site Level 3 probabilistic risk analysis (PRA) project (L3PRA project) for a two-unit pressurized-water reactor reference plant, responding to Commission direction in the staff requirements memorandum (SRM) (Agencywide Documents and Management System [ADAMS] Accession No. ML112640419) resulting from SECY-11-0089, “Options for Proceeding with Future Level 3 Probabilistic Risk Assessment (PRA) Activities” (ADAMS Accession No. ML11090A039).

Licensee information used in performing the Level 3 PRA project was voluntarily provided based on a licensed, operating nuclear power plant. The information provided reflects the plant as it was designed and operated as of 2012 and does not reflect the plant as it is currently designed, licensed, operated, or maintained. In addition, the information provided for the reference plant was changed based on additional information, assumptions, practices, methods, and conventions used by the NRC in the development of plant-specific PRA models used in its regulatory decisionmaking. **As such, use of L3PRA project reports to assess the risk from the reference plant is not appropriate and these reports will not be the basis for any regulatory decision associated with the reference plant.**

Each set of L3PRA project reports covering the Level 1, 2, and 3 PRAs for a specific site radiological source, plant operating state, and hazard group is accompanied by an overview report. The overview reports summarize the results and insights from all three PRA levels.

In order to provide results and insights better aligned with the current design and operation of the reference plant, the overview reports also provide a reevaluation of the plant risk based on a set of new plant equipment and PRA model assumptions and compare the results of the reevaluation to the original study results. This reevaluation reflects the current reactor coolant pump (RCP) shutdown seal design at the reference plant, as well as the potential impact of FLEX strategies,[4] both of which reduce the risk to the public.

A full-scope site Level 3 PRA for a nuclear power plant site can provide valuable insights into the importance of various risk contributors by assessing accidents involving one or more reactor cores as well as other site radiological sources (i.e., spent fuel in pools and dry storage casks). These insights may be used to further enhance the regulatory framework and decisionmaking and to help focus limited agency resources on issues most directly related to the agency’s mission to protect public health and safety. More specifically, potential future uses of the Level 3 PRA project can be categorized as follows (a more detailed list is provided in SECY-12-0123, “Update on Staff Plans to Apply the Full-Scope Site Level 3 PRA Project Results to the NRC’s Regulatory Framework,” dated September 13, 2012):

- enhancing the technical basis for the use of risk information (e.g., obtaining updated and enhanced understanding of plant risk as compared to the Commission’s safety goals)

- improving the PRA state-of-practice (e.g., demonstrating new methods for site risk assessments, which may be particularly advantageous in addressing the risk from advanced reactor designs, or in supporting the evaluation of the potential impact that a

[4] FLEX refers to the U.S. nuclear power industry's proposed safety strategy, called Diverse and Flexible Mitigation Capability. FLEX is intended to maintain long-term core and spent fuel cooling and containment integrity with installed plant equipment that is protected from natural hazards, as well as backup portable onsite equipment. If necessary, similar equipment can be brought from offsite.

multi-unit accident, or an accident involving spent fuel, may have on the efficacy of the emergency planning zone in protecting public health and safety)

- identifying safety and regulatory improvements (e.g., identifying potential safety improvements that may lead to either regulatory improvements or voluntary implementation by licensees)

- supporting knowledge management (e.g., developing or enhancing in-house PRA technical capabilities)

In addition, the overall Level 3 PRA project model can be exercised to provide insights with regard to other issues not explicitly included in the current project scope (e.g., security-related events or the use of accident tolerant fuel). Furthermore, some future advanced light water reactor (ALWR) and advanced non-light water reactor (NLWR) applicants may rely heavily on the results of analyses similar to those used in the L3PRA project to establish their licensing basis and design basis by using the Licensing Modernization Project (LMP) (NEI 18-04, Rev. 1) which was recently endorsed via RG 1.233. Licensees who use the LMP framework are required to perform Level 3 PRA analyses. Therefore, another potential use of the methodology and insights generated from this study is to inform regulatory, policy, and technical issues pertaining to ALWRs and NLWRs.

The results and perspectives from this report, as well as all other reports prepared in support of the Level 3 PRA project, will be incorporated into a summary report to be published after all technical work for the Level 3 PRA project has been completed.

ABBREVIATIONS AND ACRONYMS

AC:	Alternating Current
ADAPT:	Atmospheric Data Assimilation and Parameterization Techniques
AFW:	Auxiliary Feed Water
BLS:	Bureau of Labor Statistics
CCDF:	Complementary Cumulative Distribution Functions
CEC:	Commission of European Communities
CETC:	Core-Exit Thermocouple
CPI:	Consumer Price Index
CSFST:	Critical Safety Function Status Tree
DOE:	United States Department of Energy
EAB:	Exclusion Area Boundary
EAL:	Emergency Action Level
ECCS:	Emergency Core Cooling System
ED:	Emergency Director
EDG:	Emergency Diesel Generator
EPZ:	Emergency Planning Zone
ER:	Environmental Report
ESP:	Early Site Permit
ETE:	Evacuation Time Estimate
FEIS:	Final Environmental Impact Statement
FV:	Fussell-Vesely
GE:	General Emergency
ISLOCA:	Interfacing System Loss-of-Coolant Accident
LHS:	Latin Hypercube Sampling
LOCA:	Loss-of-Coolant Accident
LODI:	Lagrangian Operational Dispersion Integrator
LOOP:	Loss-of-Offsite Power
NEPA:	National Environmental Policy Act
NSCW:	Nuclear Service Cooling Water
NWS:	National Weather Service
PAG:	Protective Action Guideline
PAR:	Protective Action Recommendation
PORV:	Power-Operated Relief Valve
PWROG:	Pressurized Water Reactor Owners Group
RCP:	Reactor Coolant Pump
RCS:	Reactor Coolant System
rcy	reactor-critical-year
RVLIS:	Reactor Vessel Level Instrumentation System
SAE:	Site Area Emergency
SAPHIRE:	Systems Analysis Programs for Hands-on Integrated Reliability Evaluations
SBO:	Station Blackout
SG:	Steam Generator

SGTR:	Steam Generator Tube Rupture
SNL:	Sandia National Laboratories
SOARCA:	State of the Art Reactor Consequence Analyses
TAF:	Top of Active Fuel
WMA:	Wildlife Management Area

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1 INTRODUCTION

This report documents a description and results for the reactor, at-power, Level 3 probabilistic risk assessment (PRA) model for internal events and floods that supports the U.S. Nuclear Regulatory Commission (NRC) full-scope site Level 3 PRA project (L3PRA project) for a two-unit pressurized-water reactor (PWR) reference plant. The results provided in this report are for an accident at a single unit—a subsequent report in this series addresses multi-unit risk.

Licensee information used in performing the L3PRA project was voluntarily provided based on a licensed, operating nuclear power plant. The information provided reflects the plant as it was designed and operated as of 2012 and does not reflect the plant as it is currently designed, licensed, operated, or maintained. In addition, the information provided for the reference plant was changed based on additional information, assumptions, practices, methods, and conventions used by the NRC in the development of plant-specific PRA models used in its regulatory decisionmaking. **As such, use of this report to assess the risk from the reference plant is not appropriate and this report will not be the basis for any regulatory decision associated with the reference plant.**

Since the L3PRA project involves multiple PRA models, each of these models should be considered a "living PRA" until the entire project is complete. It is anticipated that the models and results of the L3PRA project are likely to evolve over time, as other parts of the project are developed, or as other technical issues are identified. As such, the final models and results of the project (which will be documented in a summary report to be published after all technical work for the L3PRA project has been completed) may differ in some ways from the models and results provided in the current report.

The series of reports for the L3PRA project are organized as follows:

Volume 1: Summary (to be published last)

Volume 2: Background, site and plant description, and technical approach

Volume 3: Reactor, at-power, internal event and flood PRA
- Volume 3x: Overview
- Volume 3a: Level 1 PRA for internal events (Part 1 – Main Report; Part 2 – Appendices)
- Volume 3b: Level 1 PRA for internal floods
- Volume 3c: Level 2 PRA for internal events and floods
- Volume 3d: Level 3 PRA for internal events and floods

Volume 4: Reactor, at-power, internal fire and external event PRA
- Volume 4x: Overview
- Volume 4a: Level 1 PRA for internal fires
- Volume 4b: Level 1 PRA for seismic events
- Volume 4c: Level 1 PRA for high wind events and other hazards evaluation
- Volume 4d: Level 2 PRA for internal fires and seismic and wind-related events
- Volume 4e: Level 3 PRA for internal fires and seismic and wind-related events

Volume 5: Reactor, low power and shutdown, internal event PRA
- Volume 5x: Overview

Volume 5a: Level 1 PRA for internal events
Volume 5b: Level 2 PRA for internal events
Volume 5c: Level 3 PRA for internal events

Volume 6: Spent fuel pool all hazards PRA
Volume 6x: Overview
Volume 6a: Level 1 and Level 2 PRA
Volume 6b: Level 3 PRA

Volume 7: Dry cask storage, all hazards, Level 1, Level 2, and Level 3 PRA

Volume 8: Integrated site risk, all hazards, Level 1, Level 2, and Level 3 PRA

The details of the reactor, at-power, Level 3 PRA for internal events and internal floods, are documented in this report. A discussion of the documentation approach for this report is provided in Section 1.1. Section 1.2 describes how the various sections of this report relate to the technical elements from the draft Level 3 PRA standard. Section 1.3 discusses the identification and treatment of uncertainties associated with the Level 3 PRA.

CAUTION: While the L3PRA project is intended to be a state-of-practice study, due to limitations in time, resources, and plant information, some technical aspects of the study were subjected to simplifications or were not fully addressed. As such, inclusion of approaches in the L3PRA project documentation should not be viewed as an endorsement of these approaches for regulatory purposes.

1.1 Documentation

The focus of this documentation is to enhance traceability and transparency of the technical basis for the input parameters used in MACCS code used for the L3PRA project offsite consequence analyses. Traceability is provided by ensuring that, to the extent feasible, all parameter values are traceable to a section in the report providing the technical basis for that modeling choice, which may in turn be based on primary references. Transparency is provided by, to the extent feasible, providing sufficient description of the conceptual models and summarizing references used to support the technical basis, and tracing parameters back to primary references where possible.

The L3PRA project offsite consequence analysis is intended to be a state-of-practice analysis, and as such, much of the work is based on or adapted from earlier analyses. Much of the discussion in this report is therefore based on material from earlier references. In order to provide a document which is able to be read to the maximum extent possible as a stand-alone document, text in this report has been adapted from and incorporates material from several key references to describe site conditions and to help describe or explain MACCS conceptual models and capabilities. This approach has been adopted to minimize the need for a reviewer to obtain and identify the relevant passages in those references. In such cases, the discussion has been prefaced with an explanation that the text in this report has been adapted and condensed from these references, and the section of the reference from which the information was drawn is identified so that the relevant text can be quickly located. Some significant sources of information include:

- Environmental reports submitted by the licensee for the reference plant
- A final environmental impact statement prepared by NRC staff in support of licensing actions at the reference plant
- MACCS and MACCS2 documentation (Jow et al., 1990; Chanin and Young, 1998a; Chanin and Young, 1998b)
- The technical basis for input parameter values from WASH-1400 (NRC, 1975) and NUREG-1150 (Sprung et al. 1990)
- A letter report prepared by Sandia National Laboratories (SNL) staff documenting recommendations for protective action modeling for the L3PRA project offsite consequence analyses
- A draft letter report documenting the technical basis for updated MACCS costs and protective action model parameters (Jones, Bixler and Kimura 2015)

A more complete description of the incorporated material may be obtained by consulting those references. Text has also been adapted from draft working material prepared by the staff and contractors from SNL identified as contributors to this report. This has included working material prepared specifically for the L3PRA project as well as ongoing related MACCS development work.

The document architecture for this report has been developed based on the models provided by the NUREG-1150 series of reports and the State of the Art Reactor Consequence Analyses (SOARCA) series of reports (NRC 2012; SNL 2012a; SNL 2012b; Bixler et al. 2014), together with the Technical Analysis Approach Plan and the 2010 draft ANS/ASME-58.25 (L3PRA) standard (ANS/ASME 2010). The report follows a standard format for ease of traceability. The technical basis for the input data is discussed in Section 3, with a subsection corresponding to each of the technical elements from the 2010 draft of the ANS/ASME-58.25 standard (ANS/ASME 2010). Each subsection comprises a section on assumptions (either adapted from those identified in the TAAP or identified during the development of the technical inputs as a key assumption), a technical discussion where the sources and a brief summary of the technical basis for the input parameters are provided, a summary table identifying the value of the MACCS parameters, and a section identifying key sources of uncertainty. The goal of the discussion in Section 3 is to provide, to the extent possible, a discussion of the basis for input parameters that is traceable to primary references. In many cases, inputs to the MACCS code are based on the results of other models (e.g., the source terms are generated by MELCOR[5] results and dose coefficients are contained in a dose coefficient file derived from dosimetric databases in Federal guidance reports). In such cases, the goal is to provide a traceable chain back to a well-documented product. In general, the discussion does not attempt to derive all parameters from first principles; rather, when an accepted value for a parameter from standard practice was available (e.g., parameter values from MACCS Sample Problem A that are

[5] MELCOR (Humphries, et al., 2017a, 2017b) is a code used to model accident progression in light water nuclear power plants. It models a wide variety of severe accident phenomena in a unified framework and is used to estimate severe accident source terms.

documented in [Sprung et al. 1990]), sufficient discussion is provided to understand the origin of the data, rather than attempting to redevelop the parameter value. Section 4 provides a presentation of the results in tabular form for each release category modeled by MACCS, followed by a discussion of the results. Section 5 discusses risk integration. Section 6 contains a list of known errors in the current model, as well as a list of candidates for future work. Appendices are provided for MACCS input parameters that vary by source term, and which therefore contain very large tables. Certain very large input files (i.e., the site files, the meteorological input file, and the dose coefficient files) are not reproduced in this report.

1.2 Relationship to ASME/ANS Level 3 PRA Standard

While this report was being developed, an ASME/ANS standard for Level 3 PRA was under development, and draft versions were available (ANS/ASME 2010, ASME/ANS 2015).[6] This report has been developed with the technical elements and high-level requirements defined by the draft Level 3 PRA standards in mind, but does not exactly follow the specific hierarchy defined by the supporting requirements in that document. In general, the subsections of Section 3 correspond to the technical elements identified in Section 4 of the draft standard related to model inputs. Table 1-1 shows the relationship of the technical elements from the draft Level 3 PRA standard to sections of this report. Section 4 of this report corresponds to the Conditional Consequence Quantification and Reporting technical element, as well as the Risk Integration technical element in Section 5 of the draft Level 3 PRA standard, and Section 5 of this report also corresponds to the Risk Integration technical element. For ease of discussion, some technical elements have been treated in a combined fashion; that is, because the costs captured in the economic factors technical element are all related to specific protective actions, the discussion of the protective actions and their costs are combined. In addition, the order in which the technical elements are addressed is different from that followed in the standard. The order in this document is based on the conceptual flow of a consequence calculation from release, environmental transport, exposure assessment, dose assessment, and health effects characterization. Since protective actions are generally intended to limit exposure to released radioactivity, they are therefore treated after the atmospheric transport assessment, but before the dose assessment.

Table 1-1: Relationship of technical elements from the draft Level 3 PRA standard to this report

Technical Element	Report Subsection
Radionuclide Release Characterization for Level 3	3.1
Protective Action Parameters and Other Site Data	3.4
Meteorological Data	3.2
Atmospheric Transport and Dispersion	3.3
Dosimetry	3.5

[6] The Level 3 PRA standard has since been issued for trial use and pilot application (ASME/ANS, 2017).

Health Effects	3.6
Economic Factors	3.4
Conditional Consequence Quantification and Reporting	4
Risk Estimation	4,5

The 2015 version of the draft standard was used to perform both a self-assessment and an external peer review conducted in September of 2015 by a Pressurized Water Reactor Owner's Group (PWROG)-led team on a preliminary version of this analysis. The current analysis and report incorporate feedback from that peer review.

1.3 <u>Identification and Treatment of Uncertainties</u>

There are many potential sources of uncertainty in an offsite consequence analysis, and a comprehensive listing of sources of uncertainty in an assessment of the offsite consequences from severe accidents is a challenging undertaking. For purposes of this project, staff developed an initial list of key uncertainties by a two-step process. The first step involved a review of all technical elements and a judgment of some of the key sources of uncertainty based on staff experience. Staff then supplemented this list by identifying earlier uncertainty analyses conducted using MACCS.

It should be noted that there is a difference between uncertainty (i.e., where there is a lack of knowledge about the value of a parameter or which model is most appropriate) and sensitivity (which is a measure of how much an output measure will change given a change in an input). A parameter or model may be highly uncertain, but of low importance if the results are insensitive to that parameter or model. Conversely, a parameter may be relatively well known, but the model may be highly sensitive to that parameter (e.g., model parameters that could lead to cliff-edge effects), which would magnify the impact of the uncertainty of that input. Important sources of uncertainty are those that have a combination of uncertainty and sensitivity that is sufficient to lead to a potentially significant change in model results. It should also be noted that the sensitivity of the model is a function of the particular output measure; that is, some output measures may be relatively insensitive to certain model parameters, but highly sensitive to others. This being the case, the importance of a source of uncertainty will depend upon the particular output measure being analyzed. For a project such as the L3PRA project, where the output measures range from radiological doses and radiological health effects to measures of impacted lands, impacted populations, and economic impacts, this can pose a challenge in identifying and characterizing important sources of uncertainty across the full spectrum of output measures.

A set of expert elicitations was conducted in the 1990's jointly by the U.S. Nuclear Regulatory Commission and the Commission of European Communities (hereafter referred to as the NRC/CEC expert elicitations), as documented in NUREG/CR-6244 (Harper et al. 1995), NUREG/CR-6523 (Brown et al. 1997), NUREG/CR-6526 (Goossens et al. 1997), NUREG/CR-6545 (Haskins et al. 1997), NUREG/CR-6555 (Little et al. 1997), and NUREG/CR-6571 (Goossens et al. 1998). These studies, which were based on earlier uncertainty and sensitivity

analyses using the MACCS code documented in (Helton et al. 1995 a,b,c), as well as expert judgment, covered the following phenomenological areas:

- Atmospheric dispersion and deposition of radionuclides (Harper et al. 1995)
- Behavior of deposited material and calculation of related doses (Goossens et al. 1997)
- Internal dosimetry (Goossens et al. 1998)
- Early health effects (Haskins et al. 1997)
- Late health effects (Little et al. 1997)
- Food chain (Brown et al. 1997)

In that series of reports, the variables to be elicited were chosen based on whether they had been found to be important in sensitivity studies performed in the U.S. and Europe, as well as those chosen from a joint list of important code input variables developed by CEC and U.S. consequence experts. However, there were some constraints on the identification of code input variables for the expert elicitations. For example, variables that were highly regionally dependent, such as parameters related to protective actions and economic impacts, were not considered. In addition, code input variables for which adequate information exists to develop statistical distributions were not selected for elicitation. The list of variables developed for elicitation is therefore not to be taken as a complete set, but nevertheless serves as a valuable compendium of potential sources of uncertainty. Much of the information in those documents has been converted into parameter distributions suitable for use in MACCS (Bixler et al. 2013).

Most recently, review of MACCS parameters, to identify those that are both uncertain and judged to be significant for the estimation of early and latent health effects, has been carried out as part of the SOARCA project. As part of this work, several of the recommended parameter distributions in (Bixler et al. 2013) have been revised. These more recent studies include a draft uncertainty analysis of health risks from the Surry Power Station (SNL 2015), an uncertainty analysis of health risks from the Peach Bottom Atomic Power Station (SNL 2016), and a deterministic and uncertainty analysis of health risks from the Sequoyah Nuclear Plant (SNL 2019). The most recent analysis (SNL 2019) identified the parameters listed in Table 1-2 as both epistemically uncertain and likely to have a significant effect on estimated health consequences. The aleatory uncertainty associated with meteorological variability is another source of uncertainty but is not identified in Table 1-2 because it is standard practice to include meteorological variability in MACCS analysis.

Table 1-2: Uncertain MACCS model parameters identified in the Sequoyah SOARCA report (adapted from Table 5-11 of [SNL 2019])

Deposition	Wet Deposition Coefficient (CWASH1)
	Dry Deposition Velocities (VDEPOS)
Shielding Factors	Groundshine Shielding Factors (GSHFAC)
	Inhalation Protection Factors (PROTIN)
Early Health Effects	Early Health Effects LD50 Parameter (EFFACA)
	Early Health Effects Exponential Parameter (EFFACB)
	Early Health Effects Threshold Dose (EFFTHR)
Latent Health Effects	Dose and Dose-Rate Effectiveness Factor (DDREFA)

	Lifetime Cancer Fatality Risk Factors (CFRISK)
	Long-Term Inhalation Dose Coefficients
Dispersion	Crosswind Dispersion Linear Coefficient (CYSIGA)
	Vertical Dispersion Linear Coefficient (CZSIGA)
	Time-Based Crosswind Dispersion Coefficient (CYCOEF)
Emergency Response	Keyhole Weather Forecast (KEYFORCST)
	Evacuation Delay (DLTEVA)
	Evacuation Speed (ESPEED)

Table 1-2: Uncertain MACCS model parameters identified in the Sequoyah SOARCA report (continued)

Emergency Response	Hotspot Relocation Time (TIMHOT)
	Normal Relocation Time (TIMNRM)
	Hotspot Relocation Dose (DOSHOT)
	Normal Relocation Dose (DOSNRM)

Source: adapted from Table 5-11 of (SNL 2019)

Building upon this review for the SOARCA project, the staff has developed initial lists (tables) of sources of uncertainty that follow the discussion of each technical element in this report. The entries in these tables fall into several categories. Many arise from uncertainties in the models used to develop input parameters. In general, these underlying uncertainties have not been explicitly identified. For example, source terms, dose coefficients, and risk factors used in MACCS are all based on upstream model calculations. Any uncertainties in such models would propagate forward, but (in general) no attempt was made to document the sources of uncertainty in those other models. Other uncertainties arise from the need to model processes with a range of different values (i.e., aerosol size, evacuation delays, etc.) into bins (or even a single point value) in order to make the model tractable. Other uncertainties exist as well, and additional sources of uncertainty may be identified and/or clarified as the project proceeds.

In response to comments made by the external peer review, the tables of uncertainties were expanded into a section that identifies (1) the sources of uncertainty judged to be significant to the results, (2) how the consequence model could be affected, and (3) potential sensitivity analyses that may be conducted to quantitatively examine the impact of these uncertainties. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS. In some cases, there may be no straightforward method to examine the impact of the uncertainty, and therefore no candidate sensitivity analysis is identified. For example, it could be very complex to model the impact of chemical or physical transformations of radionuclides after their release, and use of significantly different tools may be needed. Additional work could be undertaken to design analyses for such cases, if warranted. The anticipated result of each candidate sensitivity analysis, based on professional judgment, is identified. Finally, a recommended approach for carrying out each sensitivity analysis is identified.

Sensitivity analyses in MACCS can be carried out in a variety of ways, some which are very simple to implement and others which may require significant additional model development. Individual MACCS parameters may be varied by defining a distribution for the parameter in WinMACCS, which then automatically develops multiple realizations varying only that parameter. If correlations across multiple parameters can be defined, these may also be entered using the WinMACCS sampling feature. For sensitivity analyses involving correlated changes in more than one MACCS parameter value (e.g., when there are changes that are correlated across multiple MACCS parameters, such as a core inventory comprising multiple radionuclides) that are not easily defined in simple correlations, cyclic file sets may be used to redefine the value of previously defined parameters. Each cyclic file may then be run as a single

realization, capturing all of the correlated changes in a single computational realization. If a sensitivity analysis requires adding a MACCS parameter not previously defined, or which required more complex correlations resulting in changes in the model structure (i.e., using a different number of population cohorts depending upon the source term characteristics, using different weather files, etc.), development of an alternate input deck may be required. If a full probabilistic uncertainty analysis were to be performed, it is expected to be largely limited to those parameters that are amenable to parameter variations; that is, those identified as being implementable via cyclic file sets.

Schedule and resources did not permit the inclusion of these sensitivity analyses in this revision of the analysis. The identification of these analyses is therefore intended to support potential future work by clearly identifying which analyses may be productive and how they may be carried out.

2 BACKGROUND AND GENERAL INFORMATION

2.1 The MACCS Probabilistic Offsite Consequence Analysis Code

The MACCS code was selected for the offsite consequence analysis component of the L3PRA project as it is the one of the current standard code systems used for probabilistic consequence analysis, with a long pedigree, a record of continuous development, an extensive history of application to a wide variety of assessments. It also provides the capability to model a wide variety of features, events, and processes (i.e., atmospheric dispersion and deposition, exposure and dose assessment from multiple pathways, protective actions, acute and stochastic health effects, and economic impacts) in a fully coupled fashion, while allowing for probabilistic treatment of potential weather conditions at the time of the release. No other available code system was judged to have the combination of characteristics needed to support this assessment.

The evolution of probabilistic consequence modeling tools from the Reactor Safety Study in 1975 to the present day is documented in Section 1.1 of (Chanin and Young 1998a), and the following discussion is adapted from that report. The MACCS computer code includes models for atmospheric dispersion and deposition, short-term and long-term protective actions and exposure pathways, deterministic and stochastic health effects, and economic costs. Although there are many computer codes capable of modeling the effects of releases of radioactive material to the environment, MACCS is unique in its abilities for the integrated modeling because it not only treats the doses resulting from such releases, but also the effects of short-term and long-term protective actions, their associated economic costs, and the resulting deterministic and stochastic health effects. It also has the capability to automatically simulate multiple scenarios in a probabilistic manner, for example, multiple weather trials or multiple realizations for uncertain parameters, and produce probabilistic results based on sampling such inputs. Since its inception, MACCS has been used for a wide variety of purposes. At the NRC, the MACCS code has been used for a variety of assessments of the consequences of severe reactor accidents, including assessments of commercial reactor risk, spent fuel pool risk, and risks from dry storage cask accidents. MACCS is used at the NRC in support of research studies, regulatory analyses, and for estimating accident impacts for National Environmental Policy Act (NEPA) analyses.

The MACCS code has evolved from the CRAC code, which was developed to calculate the health and economic consequences of accidental releases of radioactive material to the atmosphere in support of the WASH-1400 Reactor Safety Study (NRC 1975). A follow-on code, CRAC2, was released in 1982 and featured improvements in the areas of weather sequence sampling and emergency-response modeling (Ritchie et al. 1983; Ritchie et al. 1984). The first MACCS code, released in 1987, was developed as a successor to CRAC2, to provide flexibility for the performance of sensitivity studies and the evaluation of alternative parameter values for its models. The goal of the MACCS development effort was to produce a portable code with a modular architecture and flexible database. In contrast to CRAC and CRAC2, almost all MACCS model parameters are defined by the user. Further flexibility was added in 1997 with a

major revision to address limitations associated with the limited set of radionuclides originally included in the code, which were based primarily on commercial reactor accidents. In 2001, the NRC initiated an effort to create a Windows-based interface and framework for performing consequence analyses. This effort was intended to address the following needs:

- To simplify and make more intuitive the effort required to create or modify input files
- To reduce the likelihood of user errors in performing consequence analyses
- To enable the user to simply and conveniently account for uncertainties in input data
- To displace the original batch framework with a Windows-based framework

The result of this development effort is the WinMACCS suite of codes. The WinMACCS suite of codes also includes several preprocessor codes, most notably SecPop, which is used to generate MACCS site files from census databases, and MelMACCS, which is used to convert MELCOR output files into MACCS source term parameters. WinMACCS is currently integrated with an updated version of MACCS, COMIDA2, and LHS (a code used to perform Latin hypercube sampling (LHS)) to perform all of the required functionality. The original MACCS framework is preserved; MACCS can still be run in stand-alone fashion as a batch process. The version of the code used in this analysis is WinMACCS Version 3.11.2. SecPop Version 4.3.0 was used to generate the site file, and MelMACCS Version 2.0.2 was used to process the MELCOR output files.

The MACCS code is extensively documented in several manuals, including the documentation for the original MACCS V 1.5.11 (Chanin et al. 1990; Jow et al. 1990; Rollstin et al. 1990), the two volumes of documentation released with the publication of MACCS2 (Chanin and Young 1998a; Chanin and Young 1998b), and the draft WinMACCS User’s Guide (in preparation).

2.2 General Site Information

General information about the site was obtained from an environmental impact statement prepared by NRC staff, as well as detailed information from environmental reports prepared by the licensee. The following discussion is adapted from and incorporates material from those reports.

The site comprises 1283 hectares (ha) (3169 acres [ac]) and contains two existing nuclear generating units, Units 1 and 2, which have a combined net electric generating capacity on the order of 2400 MW(e). The site boundary is located on a bluff adjacent to the bank of a large river. A large industrial complex with restricted access is located immediately across the river from the site. The site is approximately 24 km (15 mi) east-northeast of the county seat and 42 km (26 mi) southeast of a larger city. Most of the site is separated from the river floodplain by steep bluffs. The topography in the vicinity of the site consists of low rolling hills. The vicinity of the site is primarily rural undeveloped land with a few homes and small farms, with a 3160 ha (7800 ac) wildlife management area south of the site. The predominant land use classifications surrounding the site are agriculture and forest, together with the large restricted access industrial facility (predominantly forested) located across the river. Approximately 46 percent of the land in the county where the site is located is agricultural, 43 percent is forest, and 9 percent

is wetlands. Data from the USDA Cropscape database on land use for 2013 shows that the area within 40 km (25 mi) of the site is predominantly evergreen forest and wooded wetlands, with a mix of woodland and cropland (to the south and west) and woodland (to the north and east).

Table 2.2-1: Land cover within 40 km (25 miles) of the site

Woodlands (Forest and Scrubland)	72%
Cropland	19%
Open developed land	4%
Low to High Intensity developed land	4%

Within 80 km (50 mi) of the site there are residential areas in and near cities and towns, smaller communities, and farms. In the vicinity of the site, housing units are generally isolated, older single-family homes, manufactured homes, or mobile homes. The area surrounding the site is characterized by low population densities and a rural setting. Contributing to the population sparseness near the plant is the restricted access industrial complex with no permanent residents across the river. This industrial complex occupies approximately 803 km^2 (310 mi^2), approximately 20 percent of which lies within a 32 km (20 mi) radius of the site. The only population center within 16 km (10 mi) of the site is approximately 13 km (8 mi) to the southeast with a population of a few hundred. Three larger towns with populations greater than 1,000 persons are within 32 km (20 mi) of the site. The more densely populated areas in the region are more than 32 km (20 mi) from the site. A large city with over 100,000 people is located to the northwest of the site, and two towns with populations of approximately 20,000 each are located across the river to the north of the site. These cities and towns have also experienced a high rate of suburban growth in recent years.

Transients include people who work in or visit large workplaces, schools, hospitals and nursing homes, correctional facilities, hotels and motels, and at recreational areas or special events where there may be seasonal and workday variations in population. During the scheduled refueling outages, there is an influx of construction migrant labor to the area who are hired by the site to carry out fuel reloading activities, equipment maintenance, and other projects associated with the outage. This migrant population is considered as part of the site emergency planning. With the exception of the large industrial facility across the river, no significant industrial or commercial facilities are located within a 16 km (10 mi) radius of the site. The large industrial complex employs approximately 11,000 people and maintains its own emergency plan. The closest recreational areas to the site are a 7,800 acre wildlife management area south of the site and a 10,470 acre wildlife management area across the river. In addition, because of the seasonal fluctuation of labor, the agricultural sector can be another source of migrant laborers. However, the 2002 Census of Agriculture indicates the migrant population related to agricultural work is low within 80 km (50 mi) of the site.

A meteorological monitoring program has been in place since 1972. The primary meteorological monitoring system is a 60 m (197 ft) tower instrumented at the 10 m (33 ft) and 60 m (197 ft) levels. Wind speed, wind direction, wind direction fluctuation, and temperature are measured at both levels. A 45 m (148 ft) backup meteorological tower is sited nearby and provides additional

measurements of wind speed, wind direction, wind direction fluctuation, and temperature at the 10 m (33 ft) level. Data from both towers are collected and processed on a digital recording system that is located in a shelter near the base of the meteorological tower. In its review for a Final Environmental Impact Statement (FEIS), the NRC staff concluded that the system provides adequate data to represent onsite meteorological conditions as required by 10 CFR 100.20 and 10 CFR 100.21, and that the onsite data also provide an acceptable basis for making estimates of atmospheric dispersion for design-basis accident and routine releases from the plant to meet the requirements of 10 CFR Part 20, 10 CFR 50.34, and 10 CFR Part 50, Appendix I. In addition to data from the onsite meteorological monitoring program, climatological information from a nearby (approximately 32 km [20 mi] northwest of the site) National Weather Service (NWS) station, as well as climatological data from the nearby industrial facility, were reviewed for use in the FEIS. The industrial facility maintains a comprehensive meteorological observation network, and its primary observation station is 13 km (8 mi) northeast of the site. The NRC staff concluded that these stations can be used to characterize the climate at the site and surrounding region because of their comparable elevation, location within the river valley, and long period of record.

Based on onsite meteorological data collected from 1998 through 2002, the prevailing winds are from the west-southwest at both the 10 and 60 m (33 and 197 ft) levels. A secondary maximum occurs from the northeast. On a seasonal basis, the prevailing winds are from the southwest at both levels in the spring and summer. During winter, the prevailing winds are from the west; during autumn, the winds are from the northeast at both levels. This annual and seasonal wind pattern is consistent with nearby observation stations.

Atmospheric stability is a meteorological parameter that describes the dispersion characteristics of the atmosphere. Five years (1998 to 2002) of onsite temperature difference measurements made between the 60 and 10 m (197 and 33 ft) onsite meteorological tower levels indicate that unstable categories A, B, and C occur about 6 percent, 5 percent, and 7 percent of the time, respectively. Stable categories E, F, and G occur about 29 percent, 14 percent, and 11 percent of the time, respectively. Neutral conditions (category D) occur about 28 percent of the time. Seasonally, spring and summer tend to have more extremely unstable conditions because of increased solar heating occurring at the surface. Autumn and winter months exhibit more extremely stable conditions because of reduced solar heating resulting in greater radiational cooling at the surface.

Based on a 30-year period of record from 1971-2000, annual precipitation amounts average around 113 cm (44.6 in.) at the local NWS station. On average, March is the wettest month. A secondary precipitation maximum occurs during August; this maximum is the result of higher thunderstorm activity and tropical storm remnants. November is the driest month. At the large industrial facility, the annual average precipitation amount is higher; however, similar monthly and seasonal precipitation trends exist. The 5-year period (1998 through 2002) used in the analysis was an abnormally dry period in the region. Snowfall events are infrequent in the area. Annually, the region receives an average of 3.6 cm (1.4 in.) of snowfall each year. Days with snowfall in excess of 2.54 cm (1.0 in.) are rare. Freezing precipitation occurs infrequently at the site. On average, freezing precipitation occurs somewhere between 1 to 5 days per year in the

area where the site is located. A review of the National Climatological Data Center storm events database for county showed five ice storm events between 2002 and 2014, with ice accumulations ranging from one quarter to one inch.

The site is sufficiently far inland that tropical cyclones are often less than hurricane strength by the time they are in the vicinity of the site. The National Oceanic and Atmospheric Administration's Coastal Service Center (NOAA-CSC) maintains a database of tropical cyclone tracks and intensities that covers the period from 1851 through 2005. The strongest hurricane to pass within an 80 km (50 mi) radius of the site was a Category 3 hurricane, with maximum sustained surface 10 m (33 ft) winds of 49.6 m/s (111.0 mph) to 58.1 m/s (130.0 mph). Four other Category 3 hurricanes have passed within a 160 km (100 mi) radius of the site since 1851.

3 INPUT DATA

3.1 Radionuclide Release Characterization for Level 3 (RE)

3.1.1 Assumptions and Known Limitations

- The analysis uses radionuclide-specific release characteristics based on the results of the Level 2 accident progression analyses, including the quantity and form; the timing and duration; and the energy and the height of each release.
- Reactor core radionuclide inventories are determined using the ORIGEN2/SCALE computer code package at middle of cycle.
- The default list of radionuclides to be explicitly considered adequately captures the potential doses associated with radioactive releases.
- Chemical class assignments defined in MELCOR adequately capture the atmospheric dispersion and deposition properties of the released radionuclides.
- Downwash and mixing within the turbulent wake of the structures, along with a highly uncertain release location for non-stack releases, is not modeled explicitly. Instead, the physical release height elevation from the MELCOR model (corrected as necessary to elevation above grade) is used as the initial release height for the plume. This is not expected to be a significant source of uncertainty for offsite locations, which are modeled as greater than 0.75 miles from the point of release.
- Very small prolonged releases can be adequately modeled without a high degree of temporal resolution (i.e., as a single plume segment with a duration of up to 24 hours) without significantly affecting the overall analysis results.

3.1.2 Technical Discussion

A source term in MACCS is a discrete set of parameters with information on the time-dependent radionuclide release rate, plume buoyancy, and aerosol characteristics. A source term is typically associated with an estimate of the timing of any emergency declarations associated with that release. These values are computed in the Level 2 portion of the analysis using the MELCOR (Humphries et al. 2015) phenomenological model of accident progression.

Once a source term is generated, the process for importing the results of the phenomenological accident progression modeling into a form suitable for modeling of offsite consequences involves the following five steps (described in the subsections that follow):

- Identification of radionuclides and development of initial radionuclide inventory (Section 3.1.2.3)
- Assignment of radionuclides to chemical classes (Section 3.1.2.4)
- Determination of the aerosol characteristics (i.e., particle-size distribution) for each chemical class (Section 3.1.2.5)
- Characterizing the characteristics of the release path that can affect initial dispersion of the plume (Section 3.1.2.6)

- Discretization of the time-dependent radionuclide releases into plume segments (Section 3.1.2.7)

Before discussing the above steps, the use of the MelMACCS code is briefly described below, followed by a discussion of the transition of the Level 2 PRA to the Level 3 PRA (Section 3.1.2.1) and a discussion of source term characteristics important for the Level 3 analysis (Section 3.1.2.2).

The MACCS preprocessor code MelMACCS was used to assist in the process of converting the results of MELCOR computations into a format suitable for use in MACCS. The MelMACCS code relies on three sources of data: a properly formatted .ptf file generated by MELCOR; a MelMACCS initialization (.inf) file containing default parameters, such as information on core inventories and chemical class assignments, generally based on detailed ORIGEN/SCALE calculations; and user-supplied inputs. Parameters defined in the MelMACCS initialization file needed for the development of MACCS parameters are discussed in this section. MelMACCS may also be run in batch mode, with user-supplied inputs provided in a ".mel" file. This option was used in the L3PRA project MACCS models used in the documented analysis, as it provides the benefit of documenting the user-supplied inputs, and minimizes the possibility of user errors in entering input values.

3.1.2.1 *Transition from Level 2 PRA to Level 3 PRA*

The Level 2 analyses documented in (NRC 2019) are divided into two major elements: (1) severe accident sequence frequency development, which involves the use of an accident progression event tree (sometimes referred to as a containment event tree) modeled in the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) software (Smith and Wood 2011) to identify accident progression sequences and their respective frequencies; and (2) source term analysis, which involves the characterization of the release of radioactivity to the environment using the MELCOR phenomenological model. In principal, each accident progression sequence would result in a unique source term. However, because it is computationally prohibitive to develop and run models for all possible accident progression sequences, the Level 2 portion of the analysis typically selects a representative subset of the accident progression sequences for detailed quantification as input to the Level 3 analysis of offsite consequences for use in quantifying risk. These representative subsets are intended to capture the range of source term characteristics, arising from different accident progression phenomena, that could affect offsite consequences, including consideration (for example) of the magnitude and timing of the releases. These representative subsets are termed "*release categories.*" The ASME/ANS Level 3 PRA standard (ASME/ANS 2017) defines a *release category* as "a group of accident progression sequences that would generate a similar source term to the environment. Similarity in this context depends on the level of fidelity of the analysis and the number of release categories used to span the entire spectrum of possibilities. Similarity is generally measured in terms of the overall (cumulative) release of activity to the environment, the timing of the release, and (in certain applications) other physical characteristics of the source term." A detailed discussion of the process for selection/identification of release categories for the L3PRA project can be found in Section 2.5

of (NRC 2019). The resulting 16 release categories are identified in Table 2-19 of (NRC 2019), and are summarized here in Table 3.1-1.

Table 3.1-1: Summary of release categories from Level 2 analysis

Name	Description
NOCF	Containment is not bypassed or failed, and radiological release to the environment occurs via design-basis containment leakage only. This release may or may not benefit from any aerosol scrubbing.
ECF	The containment fails before or around the time of vessel breach due to an energetic event. This release may or may not benefit from any aerosol scrubbing.
ICF-BURN	The containment fails hours after vessel breach due to a global deflagration or detonation. Releases to the environment are not mitigated significantly by sprays or water pools.
ICF-BURN-SC	The containment fails hours after vessel breach due to a global deflagration or detonation. Releases to the environment benefit from scrubbing.
LCF	The containment fails tens of hours after the time of vessel breach due to long-term quasi-static overpressure. Releases to the environment are not mitigated significantly by sprays or water pools.
LCF-SC	The containment fails tens of hours after the time of vessel breach due to long-term quasi-static overpressure. Releases to the environment are mitigated by sprays and/or water pools.
BMT	The containment eventually fails due to basemat ablation due to sustained core-concrete interaction. Only the airborne component of release to the environment (which stems from normal containment leakage while the containment is pressurized) is modeled.
CIF	Release from the containment to the environment occurs via a containment penetration that fails to be isolated by the containment isolation system, or a pre-existing leakage path. The release is unmitigated.
CIF-SC	Release from the containment to the environment occurs via a containment penetration that fails to be isolated by the containment isolation system, or a pre-existing leakage path. The release is mitigated.
SGTR-C	Release from the reactor coolant system (RCS) to the environment occurs via a ruptured steam generator (SG) tubes, where the rupture occurred prior to core damage. Atmospheric relief valves (ARVs) and main steam relief valves remain predominantly closed.
SGTR-O	Release from the RCS to the environment occurs via one or more ruptured SG tubes, where the rupture occurred prior to core damage. The release is not mitigated by water above the break point on the secondary side of the affected SG. One or more secondary-side relief valves are kept open during release as a deliberate action, or fail in the open position.
SGTR-O-SC	Release from the RCS to the environment occurs via one or more ruptured SG tubes, where the rupture occurred prior to core damage. The release is mitigated by water above the break point on the secondary side of the affected SG. One or more secondary-side relief valves are kept open during release as a deliberate action, or fail in the open position.

Table 3.1-1: Summary of release categories from Level 2 analysis (continued)

Name	Description
ISGTR[7]	Release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage.
V	Release occurs from the RCS to the auxiliary building via interfacing systems LOCA. The break point may or may be not submerged. The auxiliary building remains intact.
V-F	Release occurs from the RCS to the auxiliary building via interfacing systems LOCA. The break point is not submerged. The auxiliary building fails.
V-F-SC	Release occurs from the RCS to the auxiliary building via interfacing systems LOCA. The break point is submerged. The auxiliary building fails.

Source: adapted from Table 2-19 of (NRC 2019)

The process for development of the source terms to be assigned to these release categories starts with the identification of a set of *representative sequences* from the accident progression event tree. For the reactor at-power internal events analysis, the Level 2 team identified eight representative sequences. Upon consideration of potential variants in the sequences, these cases were further refined to generate the set of base and sensitivity cases shown in Table 3.1-2.

Table 3.1-2: Representative sequence and sensitivity/recovery case descriptions

Case #	Description
1	Station Blackout (SBO) with 21 gpm per Reactor Coolant Pump (RCP) Seal Loss of Coolant Accident (LOCA), Indefinite Auxiliary Feedwater (AFW), and Rapid Depressurization
1A	Base-case SBO with Eventual Loss of AFW
1A1	Base-case SBO with Eventual Loss of AFW, and Suppressed Deflagrations
1A2	Base-case SBO with Eventual Loss of AFW and Late Combustion-Induced Containment Failure
1B	Base-case SBO with Initial Loss of AFW, and No Depressurization
1B1	Base-case SBO with Initial Loss of AFW, No Depressurization, and 182 gpm per RCP seal LOCA
1B2	Base-case SBO with Initial Loss of AFW, No Depressurization, and Stuck-Open Power-Operated Relief Valve (PORV)
2	Transient Induced by Total Loss of Nuclear Service Cooling Water (NSCW), 182 gpm per RCP Seal LOCA, AFW and Controlled Depressurization
2R1	Base case with Severe Accident Management Guideline (SAMG)-prompted Additional Secondary-Side Cooldown During Core Damage

[7] In this report and elsewhere, the acronyms ISGTR (induced steam generator tube rupture) and TI-SGTR (temperature-induced steam generator tube rupture) are used interchangeably. Meanwhile, the term C-SGTR (consequential steam generator tube rupture) is used to more broadly capture both TI-SGTRs and the PI-SGTRs (pressure-induced steam generator tube ruptures) considered in the Level 1 PRA.

Table 3.1-2: Representative sequence and sensitivity/recovery case descriptions (continued)

Case #	Description
2R2	Base case with SAMG-prompted Firewater-based Containment Spray Following Vessel Breach
2A	Base case with Containment Failure Forced at the Time of Vessel Breach
3	Transient Initiated by Loss of Main Feedwater, AFW Lost at 3 Hours, and Emergency Core Cooling System (ECCS) Unavailable
3A1	High-Pressure Transient, with Instrument Tube Failure
3A2	High-Pressure Transient, with Induced Rupture of Steam Generator (SG) Tubes
3A3	High-Pressure Transient, with Induced Ruptures of SG Tubes and Hot Leg Nozzle
3A4	High-Pressure Transient, with All Induced RCS Failure Paths Disabled
4	Transient Induced by Electrical Distribution and NSCW Failures, 182 gpm per RCP Seal LOCA,AFW, and Controlled Depressurization
5	Interfacing System Loss of Coolant Accident (ISLOCA) with Submerged Break
5A	Base-case ISLOCA but with Uncovered Break
5B	Base-case ISLOCA but with Double-Ended Eight-Inch Break
5C	Base-case ISLOCA with Plugging of PPAFES Filters
5D	Base-case ISLOCA but with Double-Ended Eight-Inch Uncovered Break
6	Transient Initiated by Loss of Offsite Power, AFW Lost at 6 Hours, ECCS Available, and Containment Cooling Available
6R1	Base case with SAMG-prompted Low-Pressure Injection Initiated During Core Damage
6A	Base case with Containment Sprays Actuating After Core Damage
6B	Base case with Deflagrations Suppressed
6C	Base case with Containment Failure Forced at the Time of Vessel Breach
6D	Case 6A with Containment Failure Forced at the Time of Vessel Breach
7	Station Blackout with 21 gpm per RCP Seal LOCA, AFW Lost at 4 hours, and Containment Isolation Failure
7A	Base case with Portable Pump Injection through Containment Spray Lines
8	Un-isolated Steam Generator Tube Rupture (SGTR) with AFW
8R1	Base case with SAMG-prompted Flooding of Ruptured SG During Core Damage
8R2	Base case with SAMG-prompted Flooding of Ruptured SG Following Vessel Breach
8A	Base-case SGTR with AFW Supplied to Affected SG
8B	Base-case SGTR with Stuck-Open Relief Valve in Affected Steam Generator
8BR1	Case 8B with SAMG-prompted Flooding of Ruptured SG During Core Damage

Source: adapted from Table 2-4 of (NRC 2019)

The results from the phenomenological model, summarized in the .ptf file generated by MELCOR, are known as *source terms*. Each of these modeling cases, which represents the set of all representative sequences considering both sensitivities and recovery actions, is modeled using the MELCOR phenomenological model.

As discussed in Sections 2.5 and 2.7 of (NRC 2019), each of these source terms is assigned to a release category. For situations where more than one source term could be assigned to a release category, the Level 2 team selected a single source term to be used to represent the release category (which in this document is termed the *representative source term* for that release category), and identified the other source terms (which in this document are termed *alternate source terms*) that could be used to estimate the consequences from that release category.

In this analysis, each of the representative source terms was analyzed using the MACCS computer code. The base-case analyses only include the representative source terms, but the alternate source terms are candidates to be analyzed as part of a sensitivity analysis. This would allow an evaluation of the adequacy of the process for binning each of the MELCOR source terms into release categories, and can serve to verify that the source term selected to represent each release category is appropriately representative.

The binning of source terms into release categories needs to be completed as part of the Level 2 analysis before the Level 3 analysis is started. Section 2.5.2.3 of (NRC 2019) discusses the use of the preliminary offsite consequence analyses to inform source term selection for the Level 2 analysis, by examining the variability within representative and alternate source terms for a given release category.

In a preliminary version of these analyses, the results of MELCOR modeling of the source terms were reviewed by NRC and SNL experts in accident progression and emergency response using information from the MELCOR phenomenological model. The emergency action level (EAL) scheme from the site emergency plan was used to identify when EALs would be reached, and therefore, when the declaration of an accident class, such as a site area emergency (SAE) or a general emergency (GE), would be expected for that MELCOR source term. The results of this review suggested that the approach used to develop proposed EAL timings based on plant conditions recommended by the Level 2 team was reasonable. The recommended EAL timings corresponding to the MELCOR source terms provided by the Level 2 team are therefore used in this analysis. The recommendations are summarized in Table 3.1-3 below, reproduced from Table 2-20 of (NRC 2019). Timings are relative to the time of occurrence of the initiating event and are based on plant-specific information that is typically proprietary and not included here.

Table 3.1-3: EAL declaration times

Representative Sequence No.	Alert Declaration* (hr)	Site Area Emergency Declaration (hr)*	General Emergency Declaration (hr)*
1	~0	0.25	3
1A	~0	0.25	3

Representative Sequence No.	Alert Declaration* (hr)	Site Area Emergency Declaration (hr)*	General Emergency Declaration (hr)*
1A1	~0	0.25	3
1A2	~0	0.25	3

Table 3.1-3: EAL declaration times (continued)

Representative Sequence No.	Alert Declaration* (hr)	Site Area Emergency Declaration (hr)*	General Emergency Declaration (hr)*
1B	~0	0.25	3
1B1	0	0.25	2.5
1B2	0	0.25	3
2	1	7	8
2A	1	7	8
3	0.25	5	8
3A1	0.25	5	8
3A2	0.25	5	8
3A3	0.25	5	8
3A4	0.25	5	8
4	2.25	8	17
5	0.25	0.25	7.5
5A	0.25	0.25	7.5
5B	0.25	0.25	1.25
5C	0.25	0.25	7.5
5D	0.25	0.25	1.25
6	2.5	13	13
6A	2.5	13	13
6B	2.5	13	13
6C	2.5	13	13
6D	2.5	13	13
7	~0	0.25	3
7A	~0	0.25	3
8	0.25	38	47
8A	0.25	70	90
8B	0.25	38	47

Source: reproduced from Table 2-20 of (NRC 2019)

The list of MELCOR source terms, and the timing of the expected GE declaration for each, is summarized in Table 3.1-4. The representative source terms are listed in in bold font.

Table 3.1-4: Release category summary table for the Level 3 PRA team

Release Category	Freq. (/yr)[1]	MELCOR Modeling Case	Core Damage (hr)[2]	GE (hr)	Major Release (hr)[3]	Cumul. Iodine Rel. Frac.	Cumul. Cesium Rel. Frac.
V-F	$1{\times}10^{-7}$	**5D**	**2.8**	**1.25**	**3.2**	**1.4E-1**	**1.3E-1**
V-F-SC	$2{\times}10^{-7}$	**5B**	**2.8**	**1.25**	**3.2**	**1.2E-1**	**9.2E-2**
		5C	*9.5*	*7.5*	*10*	*1.5E-3*	*7.8E-4*

Table 3.1-4: Release category summary table for the Level 3 PRA team (continued)

Release Category	Freq. (/yr)[1]	MELCOR Modeling Case	Core Damage (hr)[2]	GE (hr)	Major Release (hr)[3]	Cumul. Iodine Rel. Frac.	Cumul. Cesium Rel. Frac.
V	$<7{\times}10^{-8}$	**5**	**9.5**	**7.5**	**10**	**1.1E-3**	**6.4E-4**
		5A	*9.5*	*7.5*	*10*	*6.8E-4*	*6.3E-4*
SGTR-O	$<7{\times}10^{-8}$	**8B**	**50**	**47**	**51**	**3.4E-1**	**2.5E-1**
SGTR-O-SC	$2{\times}10^{-7}$	**8BR1**	**50**	**47**	**51**	**9.1E-3**	**1.0E-2**
SGTR-C	$<7{\times}10^{-8}$	**8**	**50**	**47**	**52**	**1.2E-2**	**1.1E-2**
		8A	*96*	*90*	*97*	*9.4E-3*	*8.3E-3*
		8R1	*50*	*47*	*Never*	*5.9E-4*	*6.4E-4*
		8R2	*50*	*47*	*52*	*1.1E-2*	*1.1E-2*
ISGTR (a.k.a., C-SGTR)	$6{\times}10^{-7}$	**3A2**	**11**	**8**	**11**	**2.3E-1**	**9.2E-2**
		3A3	*11*	*8*	*11*	*7.6E-2*	*3.8E-2*
CIF	$<7{\times}10^{-8}$	**7**	**16**	**3**	**21**	**4.2E-2**	**3.4E-2**
CIF-SC	$<7{\times}10^{-8}$	**7A**	**16**	**3**	**18**	**3.3E-2**	**2.5E-2**
ECF	$<7{\times}10^{-8}$	**2A**	**15**	**8**	**22**	**1.5E-1**	**1.6E-1**
		6C	*15*	*13*	*40*	*6.1E-3*	*3.2E-3*
		6D	*15*	*13*	*74*	*7.7E-4*	*2.2E-3*
LCF	$2.9{\times}10^{-5}$	*1A*	*16*	*3*	*75*	*3.7E-3*	*4.2E-3*
		1A1	*16*	*3*	*76*	*2.7E-3*	*3.8E-3*
		1B	**3.9**	**3**	**55**	**1.2E-2**	**9.9E-3**
		1B1	*3.0*	*2.5*	*56*	*1.6E-2*	*1.0E-2*
		1B2	*3.3*	*3*	*64*	*8.2E-3*	*4.3E-2*
		2	*15*	*8*	*99*	*2.0E-3*	*4.2E-3*
		3	*11*	*8*	*62*	*2.4E-2*	*1.5E-2*
		3A1	*11*	*8*	*58*	*1.2E-2*	*6.9E-3*
		3A4	*11*	*8*	*71*	*1.5E-2*	*9.9E-3*
		4	*15*	*17*	*99*	*2.2E-3*	*5.2E-3*
LCF-SC	$3{\times}10^{-6}$	**2R2**	**15**	**8**	**128**	**6.0E-4**	**1.7E-3**
ICF-BURN	$9{\times}10^{-6}$	**1A2**	**16**	**3**	**28**	**4.3E-2**	**3.2E-2**
ICF-BURN-SC	$2{\times}10^{-6}$	**1A2 (truncated at ~28 hrs)**	**16**	**3**	**28**	**6.9E-5**	**5.9E-5**
BMT	$8{\times}10^{-7}$	**6**	**15**	**13**	**Never**	**6.4E-5**	**5.4E-5**

Release Category	Freq. (/yr)[1]	MELCOR Modeling Case	Core Damage (hr)[2]	GE (hr)	Major Release (hr)[3]	Cumul. Iodine Rel. Frac.	Cumul. Cesium Rel. Frac.
		6A	*15*	*13*	*Never*	*4.4E-6*	*3.0E-6*
		6B	*15*	*13*	*Never*	*8.2E-5*	*7.9E-5*

Table 3.1-4: Release category summary table for the Level 3 PRA team (continued)

NOCF	2.4×10^{-5}	*1*	*139*	*3*	*Never*	*1.1E-4*	*7.4E-5*
		2R1	**15**	**8**	**Never**	**8.5E-5**	**7.4E-5**
		6R1	*15*	*13*	*Never*	*1.4E-5*	*1.2E-5*

Source: adapted from Table 2-26 of (NRC 2019)

Note: Freq: Frequency; Cumul.: Cumulative; Rel. Frac: Release Fraction

[1] Values less than 0.1 percent of total release frequency are listed as being less than 7×10^{-8}/yr (0.1 percent of total release frequency), so as not to over-state the accuracy of the model. All frequencies represent the longest accident termination time considered (i.e., 3 days for ISLOCAs and 7 days for other accidents). These cases are modeled with a frequency equal to 7×10^{-8}/yr.

[2] This represents the time at which peak nodal clad temperature exceeds 1204C (2200F).

[3] This has been based on the time at which integral environmental Xenon class release exceeds 10 percent, or Iodine class release exceeds 1 percent (whichever comes first). This is simply intended to provide a sense of the delta between the initial gap release from the hottest group of fuel assemblies versus the time at which a notable fraction of the noble gases or volatiles have reached the boundary with the environment.

3.1.2.2 *Discussion of Source Term Characteristics Important for Level 3 PRA Analyses*

The characteristics of the release categories most important to offsite consequences are the magnitude of the release and the warning time. The warning time is the time available between the declaration of a GE and the onset of a major release. Estimation of a single warning time for a particular source term is somewhat complex for this analysis, both because cohorts beyond the EPZ may be assumed to receive an evacuation order after GE, and because the keyhole evacuation model used in this analysis will not trigger an evacuation order for areas outside the circular portion of the keyhole until several hours before the wind is projected to shift. Therefore, for individuals located outside of the 5-mile circular evacuation region, the decision to evacuate may come at a range of times after the declaration of a GE. In addition, because some source terms may exhibit a period of low-level releases before the onset of a major release due to containment failure, and other source terms may never result in a large release, defining the time at which the release begins (in order to quantify the warning time) may be challenging. However, since the area within several miles of the site is likely to be the region where exposures are the most elevated, and since the potential low levels of release prior to a major release are not likely to result in high exposures, the warning time is defined in this analysis as the difference between the time at which a GE is declared and the time at which the major release begins. The values for these properties were provided in Table 3.1-4.

As seen in Figures 3.1-1 and 3.1-2, the LCF and ICF-BURN release categories (both of which were modeled with source terms based on station blackout scenarios, as see in Tables 3.1-2 and 3.1-4), and to a lesser extent the ISGTR release category (a bypass scenario), contribute the most to the frequency-weighted mean release fractions for cesium and iodine. The cesium and iodine chemical groups have been selected for illustrative purposes because these two chemical groups contain isotopes are likely to be important for early (I-131) and late (Cs-134 and Cs-137) health effects. Other isotopes may also be important to dose. For example, the SOARCA studies show that tellurium (Te) is the dominant radionuclide group for latent health effects when different dose-response models are used (e.g., see NUREG/CR-7110, Vol 2, Figures 7-13 to 7-20). The relative contribution of release categories to the frequency-weighted

mean release fraction may vary by the chemical group considered. However, to the extent that releases in one chemical group (e.g., I) are correlated to releases in a difference chemical group (e.g., Te), the relative ranking of release categories is not expected to vary significantly, at least for volatile chemical groups such as iodine and tellurium.

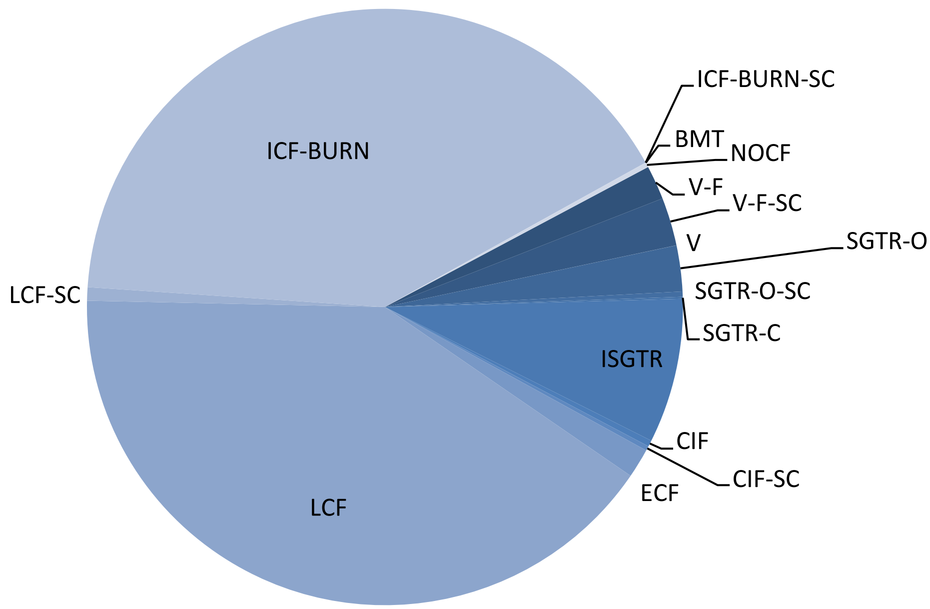

Figure 3.1-1: Relative contribution of release categories to frequency-weighted mean cesium release fraction

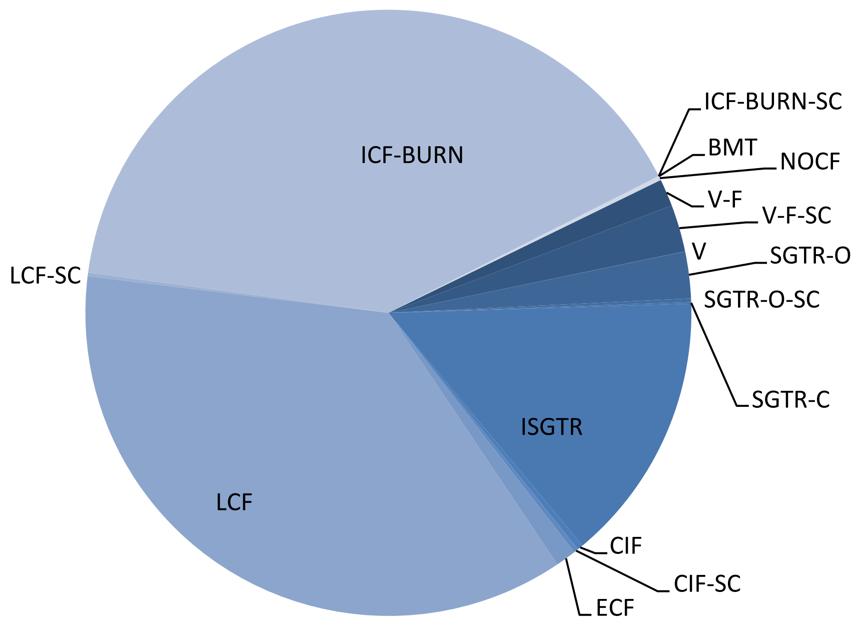

Figure 3.1-2: Relative contribution of release categories to frequency-weighted mean iodine release fraction

The time dependence of the release is illustrated by plotting the cesium release fraction as a function of time for each of the release categories. This is plotted against two different time scales. In Figure 3.1-3, the cesium release fraction is plotted against the accident initiation time. This shows the characteristics of the release. Many of the releases are characterized by "pulse" type releases, characterized by a steep increase in the cumulative release fraction. These may occur relatively early, as exemplified by the bypass scenarios V, V-F, and V-F-SC, or late, as in some of the SGTR release categories. In contrast, some of the releases are more prolonged, most notably the LCF and LCF-SC release categories. Finally, several release categories exhibit both low and prolonged releases, such as the NOCF and BMT release categories. Other scenarios, such as the ECF, ICF, and CIF release categories, are more delayed than the bypass scenarios but rise sharply once they begin.

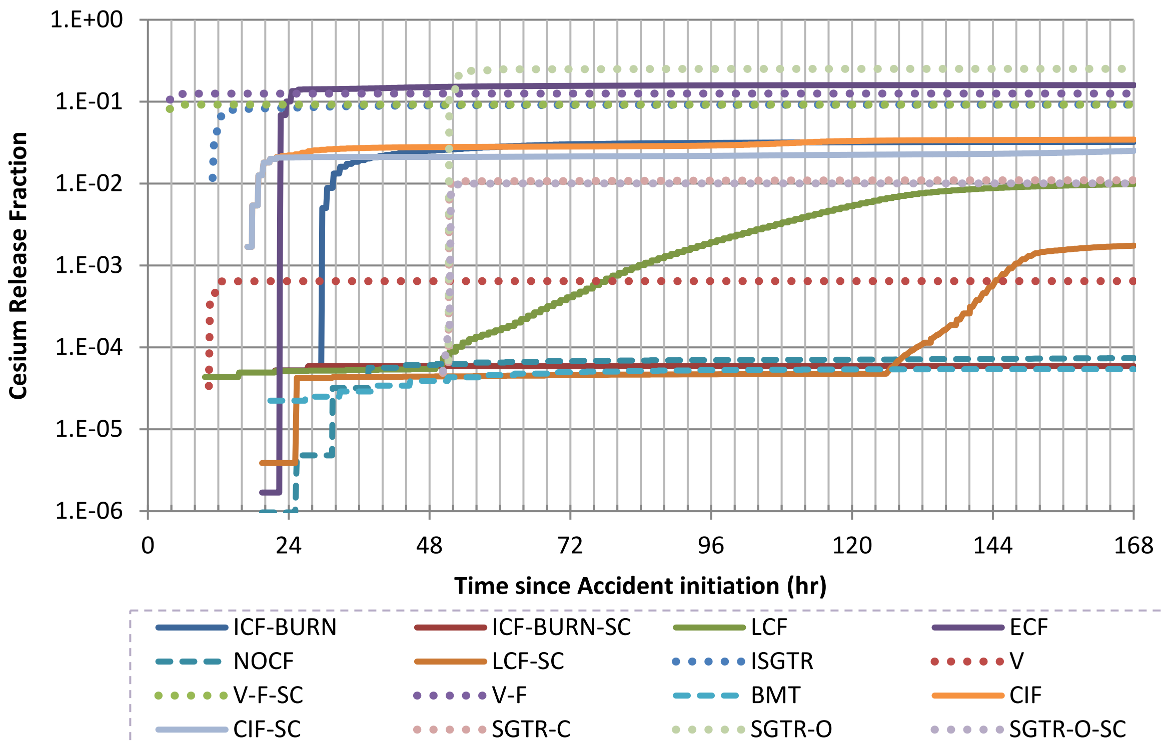

Figure 3.1-3: Cesium release fractions, relative to accident initiation time
Note: Bypass scenarios are plotted with a dotted line. Release categories with no containment failure to the atmosphere (BMT and NOCF) are plotted with dashed lines

Because some of these scenarios may not be projected to result in a GE until relatively long into the accident, the release curves are also plotted against the warning time in Figure 3.1-4. This curve is generated by subtracting the GE time for each scenario from its time of release and demonstrates that a brief warning time can result either from a rapid onset of release (e.g., ISLOCA scenarios) or from a relatively delayed GE declaration time (e.g., SGTR scenarios). However, the relatively long delay prior to release for some of the more delayed SGTR release scenarios may still allow substantial time for the decay of very short lived radioactivity with half-lives on the order of hours, an effect which is not captured in Figure 3.1-4.

Additional characteristics that may be important, but which have not yet been specifically analyzed, include the source term characteristics that affect plume rise (such as the parameters that affect the buoyancy flux of the released plume segments) and the particle-size distribution, which will affect the dry deposition velocity. The effect of plume rise and dry deposition velocity could be examined using sensitivity analyses to determine whether the variation in these attributes of the source term are significant for the offsite consequence analyses.

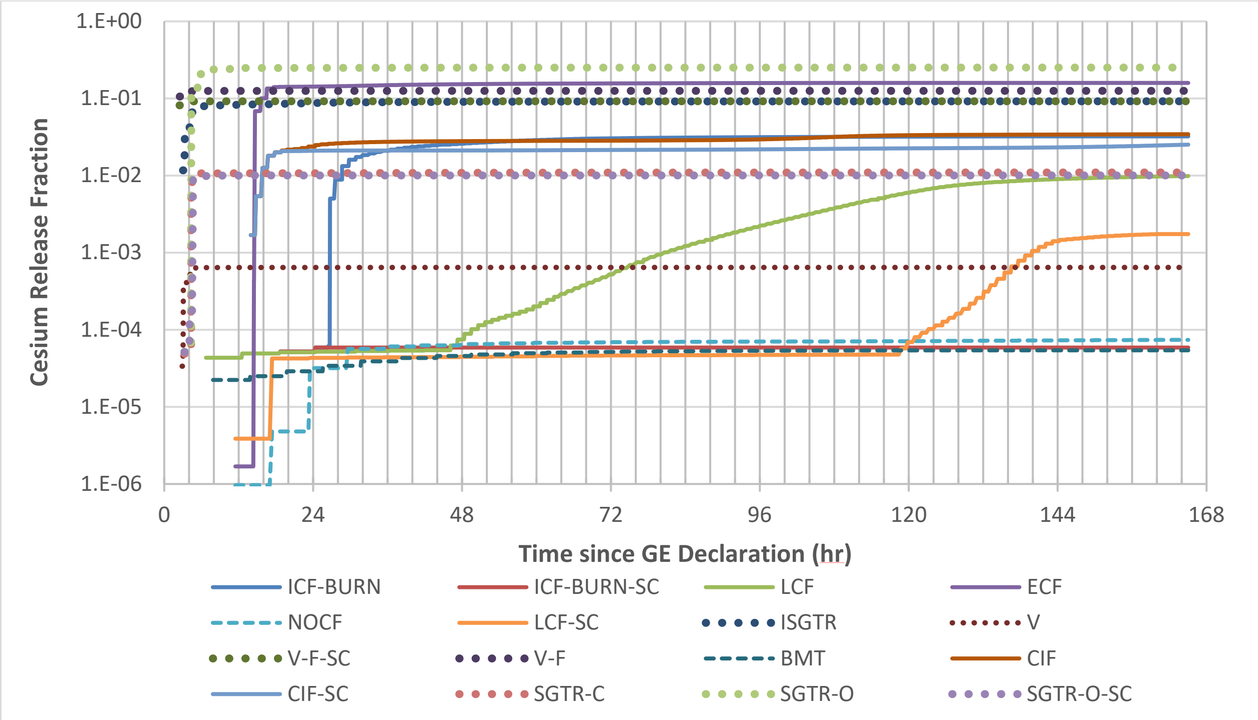

Figure 3.1-4: Cesium release fractions, relative to GE declaration time
Note: Bypass scenarios are plotted with a dotted line. Release categories with no containment failure to the atmosphere (BMT and NOCF) are plotted with dashed lines

3.1.2.3 *Identification of Radionuclides and Development of Initial Radionuclide Inventory*

In principle, a very large number of radionuclides is present in an operating reactor core. However, not all of these isotopes are significant in the determination of offsite consequences. For example, some radionuclides have half-lives on the order of seconds (s) to minutes (m), and thus will decay into a stable form long before they can be released into the environment. Others, because of the characteristics of the emitted radiation or with a low volatility leading to a low release fraction, do not significantly contribute to a radiological dose. The process for identifying radionuclides for inclusion in the analysis is described in Sections 3.3 and 8.2.1 of Appendix VI of WASH-1400 (NRC 1975). The list currently used is provided in Table 3.1-5 and includes the 54 radionuclides considered in WASH-1400, plus six additional radionuclides (Sr-92, Y-92, Y-93, Ba-139, La-141, and La-142) added at the time of NUREG-1150 (NRC 1990) and an additional 11 nuclides to allow for explicit consideration of doses from progeny. Two nuclides (Sb-127 and Sb-129), considered at the time of WASH-1400 and NUREG-1150, were not explicitly evaluated in the SOARCA project and were therefore not included here. It may be noted that because the basis for the exclusion of Sb-127 and Sb-129 is unclear, it is recommended that future analyses include these two radionuclides.

Table 3.1-5: Radionuclides modeled in the L3PRA project

Co-58	Zr-97	Te-132	Ce-141
Co-60	Nb-95	I-131	Ce-143
Kr-85	Nb-97	I-132	Ce-144
Kr-85m	Nb-97m	I-133	Pr-143
Kr-87	Mo-99	I-134	Pr-144
Kr-88	Tc-99m	I-135	Pr-144m
Rb-86	Ru-103	Xe-133	Nd-147
Rb-88	Ru-105	Xe-135	Np-239
Sr-89	Ru-106	Xe-135m	Pu-238
Sr-90	Rh-103m	Cs-134	Pu-239
Sr-91	Rh-105	Cs-136	Pu-240
Sr-92	Rn-106	Cs-137	Pu-241
Y-90	Te-127	Ba-137m	Am-241
Y-91m	Te-127m	Ba-139	Cm-242
Y-91	Te-129	Ba-140	Cm-244
Y-92	Te-129m	La-140	
Y-93	Te-131	La-141	
Zr-95	Te-131m	La-142	

As described in Section 5.4 of the MACCS2 user’s guide (Chanin and Young 1998a), MACCS automatically accounts for decay and ingrowth of these radionuclides with data supplied by the Radiation Shielding Information Center as part of the FGR-DOSE/DLC-167 data package, included in the INDEXR.DAT file used by MACCS. This requires that decay progeny that produce a significant dose (e.g., Ba-137m) be included in the list of radionuclides. Some of the decay products of the radionuclides listed in Table 3.1-5 are very long-lived and are not significant contributors to dose. Although these nuclides must be identified in MACCS to ensure that the decay is properly accounted for, they may be designated as “pseudostable“ in order to avoid the unnecessary computational expense of accounting for the negligible contribution from these nuclides. The pseudostable nuclides included in the Level 3 PRA are identified in Table 3.1-6.

Table 3.1-6: Pseudostable radionuclides

I-129	Sm-147	U-237	Nb-93m
Xe-131m	U-234	Np-237	Nb-95m
Xe-133m	U-235	Rb-87	Tc-99
Cs-135	U-236	Zr-93	Pm-147

The core radionuclide inventories for each of the radionuclides listed in Table 3.1-5 are based on those used for the Level 2 analysis. The inventories were calculated using results from a SCALE/ORIGEN calculation performed by Oak Ridge National Laboratory (ORNL) based on middle-of-cycle trip. The decay heats, masses, and activities as a function of time were processed and used as inputs to the MELCOR simulations identified in Table 3.1-2 to define

decay heat and chemical masses, and as inputs to MACCS to define the radionuclide inventory. The initial radionuclide inventory can either be defined directly in the MACCS input deck or it can be generated by MELMACCS based on a predefined MELMACCS inventory file. For this analysis, the MELMACCS inventory files provided by ORNL, after correction to remove duplicate inventory entries for both mass and activity, were used in conjunction with MELMACCS to generate the core inventory. The core radiological inventories based upon the corrected MELMACCS inventory files are shown in Table 3.1-7.

Table 3.1-7: Initial core inventory (Bq), middle of cycle trip from 100% power

Kr-85	2.75E+16
Kr-85m	1.07E+18
Kr-87	2.13E+18
Kr-88	2.82E+18
Xe-133	7.54E+18
Xe-135	1.89E+18
Xe-135m	1.56E+18
Cs-134	3.30E+17
Cs-136	9.52E+16
Cs-137	2.63E+17
Rb-86	5.32E+15
Rb-88	2.86E+18
Ba-139	6.76E+18
Ba-140	6.53E+18
Sr-89	3.92E+18
Sr-90	2.03E+17
Sr-91	4.88E+18
Sr-92	5.19E+18
Ba-137m	2.51E+17
I-131	3.57E+18
I-132	5.32E+18
I-133	7.47E+18
I-134	8.49E+18
I-135	7.13E+18

Te-127	2.79E+17
Te-127m	2.27E+16
Te-129	8.85E+17
Te-129m	1.30E+17
Te-131m	6.40E+17
Te-132	5.13E+18
Te-131	3.10E+18
Rh-105	2.87E+18
Ru-103	5.06E+18
Ru-105	3.28E+18
Ru-106	1.18E+18
Rh-103m	5.01E+18
Rh-106	1.42E+18
Nb-95	6.25E+18
Co-58	2.33E+07
Co-60	2.35E+11
Mo-99	6.84E+18
Tc-99m	6.28E+18
Nb-97	6.56E+18
Nb-97m	6.20E+18
Ce-141	6.12E+18
Ce-143	5.86E+18
Ce-144	3.79E+18
Np-239	6.46E+19

Pu-238	4.67E+15
Pu-239	9.51E+14
Pu-240	1.07E+15
Pu-241	2.79E+17
Zr-95	6.42E+18
Zr-97	6.52E+18
Am-241	2.67E+14
Cm-242	6.61E+16
Cm-244	3.74E+15
La-140	6.64E+18
La-141	6.17E+18
La-142	5.98E+18
Nd-147	2.39E+18
Pr-143	5.87E+18
Y-90	2.11E+17
Y-91	5.01E+18
Y-92	5.25E+18
Y-93	5.80E+18
Y-91m	2.88E+18
Pr-144	3.83E+18
Pr-144m	6.03E+16
Total	7.76E+20

3.1.2.4 *Chemical Class Assignments*

Radionuclides are grouped into a discrete set of chemical groups, which are groups of elements that have similar chemical properties (e.g., volatility and tendency to interact with other elements, particularly with steam and oxygen) that determine how much of the mass present in the core will be released. These assignments are defined by MELCOR and are also defined in the initialization file for MelMACCS. The current usage in MACCS is based on updates to the MELCOR code (Table 2.1 of [Humphries et al. 2015]). For this project, the nine chemical classes listed in Table 3.1-8 are included. Although cesium iodide (CsI) and cesium molybdate (Cs_2MoO_4) are included separately in the release calculation performed by MELCOR,

MELMACCS processes these chemical classes by splitting them into subclasses. CsI is split into Class 2, Cesium (Cs), and Class 4, Halogens (I), according to their mass fractions. Cs_2MoO_4 is split into Class 2, Cesium (Cs), and Class 7, Molybdenum (Mo), according to their masses. Specifically,

- 49 percent of the mass in the CsI class is assigned to the halogen (I) class
- 51 percent of the mass of the CsI class and 73 percent of the mass in the Cs2MoO4 class is assigned to the alkali metal (Cs) class
- 27 percent of the mass in the Cs2MoO4 class is assigned to the Early Transition element (Mo) class

Table 3.1-8: Radionuclide chemical groups

Class	Name	Representative Element	Member Elements*
1	Noble Gas	Xe	He, Ne, Ar, Kr, Xe, Rn, H, N
2	Alkali Metals	Cs	Li, Na, K, Rb, Cs, Fr, Cu
3	Alkali Earths	Ba	Be, Mg, Ca, Sr, Ba, Ra, Es, Fm
4	Halogens	I	F, Cl, Br, I, At
5	Chalcogens	Te	O, S, Se, Te, Po
6	Platinoids	Ru	Ru, Rh, Pd, Re, Os, Ir, Pt, Au, Ni
7	Early Transition Elements	Mo	V, Cr, Fe, Co, Mn, Nb, Mo, Tc, Ta, W
8	Tetravalent	Ce	Ti, Zr, Hf, Ce, Th, Pa, Np, Pu, C
9	Trivalents	La	Al, Sc, Y, La, Ac, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Am, Cm, Bk, Cf

Source: Table 2.1 of (Humphries et al. 2015)
**Elements included in Table 3.1-5 are underlined.*

3.1.2.5 *Aerosol Characteristics*

The physical and chemical form of the radionuclides can have a strong effect on the transport of released radioactivity in the atmosphere, most notably by controlling the rate at which the aerosols are depleted by dry deposition. This is captured in this analysis by defining the distribution of particle sizes for each chemical group, and using this to determine the particle deposition velocity (described in Section 3.3.1.6 of this document). MELCOR generates a time-dependent distribution of particle sizes for each chemical group released to the environment. Noble gases are assumed to be non-depositing. Because MACCS cannot account for a time-dependent distribution of particle sizes over the course of a modeled release, MELMACCS assigns the particle-size distribution for each chemical group by integrating, over the entire period of the release, both the total mass released and the mass released for each particle-size group. The particle-size distribution for a given chemical group is defined by the ratio of the mass released for each particle-size distribution to the total mass released. The particle-size bins are defined as an input in MELCOR. The median diameter for the particle-size bins for the MELCOR analyses used to generate the source terms are given in Table 3.1-9. The resulting particle-size distribution data for each chemical class and each release category are provided in

Appendix A, Table A.1b. The dry deposition velocities corresponding to these aerosol sizes are discussed in Section 3.3.2.6.

Table 3.1-9: Aerosol size bin definitions (mass median aerosol diameter, micrometers [μm])

Bin Number	1	2	3	4	5	6	7	8	9	10
MMAD (μm)	0.15	0.29	0.53	0.99	1.8	3.4	6.4	12	22	41

3.1.2.6 *Plume Release Path Characterization*

The MACCS atmospheric dispersion models, discussed in more detail in Section 3.3 of this document, require specification of the elevation of the release (PLHITE), as well as the building height (BUILDH) and initial plume height (PLSIGYINIT) and width (PLSIGZINIT). These parameters are characteristics of the physical location of the release path modeled in MELCOR, and are summarized in Table 2-27 of (NRC 2019). As summarized in Table 3.1-10, there are several potential locations where radioactivity could be released to the environment in the case of a severe accident.

For the normal leakage and overpressure failure pathways, there is considerable uncertainty in the location of the potential failure. The source can be distributed over the surface area of the structure from which the release occurs or located at any point on the structure. Because portions of the containment are below grade, releases to the environment from containment failures below grade would occur through access shafts, which could be at ground level, and/or into adjacent structures, with subsequent releases at elevations above ground level. Releases could also occur from airlocks and hatches at a variety of different locations and elevations. Auxiliary building failure may occur at the roof or at other locations on the auxiliary building. Furthermore, roof elevations of the different structures can be variable. However, all of these points are likely to result in releases into the building wake created by the complex of structures that includes the containment, the control building, the fuel handling building, the auxiliary building, and the turbine building. A number of processes associated with the building wake will act to modify the characteristics of the release as it begins to be transported downwind; see Section 7-8.3.3 of (Hosker 1984) for a discussion of the effects of wakes from building clusters on effluent releases. For example, there can be a high degree of mixing associated with the turbulent wake created by air passing over the building from which the materials are released, as well as adjacent structures, which can cause a rapid initial dispersion upon release. Furthermore, wake effects may result in a plume released from an elevated location (but still within the wake) to be brought down closer to the ground surface, particularly at high wind speeds; conversely, ground-level releases can be elevated under low wind speed conditions. The complex of buildings presents a different set of crosswind profiles depending upon the direction of the wind. The containment building is approximately 45 m in diameter and extends approximately 55 m above grade, and the adjacent structures are somewhat lower. Project staff have elected to follow the standard MACCS practice of using the dimensions of the structure from which the release occurs to evaluate wake effects, and the elevation of the MELCOR

pathway to define the initial release height. To simulate the effect of turbulent mixing within the building wake, these dimensions are used to define the initial size of the plume (initial sigma-y and sigma-z), as discussed in Section 3.3.2.2. The effect of the uncertainty in building height and width is not expected to be significant, based on the sensitivity analyses documented in NUREG/CR-6135 (Helton et al.1995b), as also discussed in Section 3.3.2.2. The effective building height is also used for computing plume liftoff of buoyant plumes under low wind speed conditions, as discussed in Section 3.3.2.3.

Given the uncertainty in potential release locations, the initial release height is assumed to be the elevation of the MELCOR release pathway, consistent with SOARCA modeling practice. The effect of uncertainty in release elevation was assessed in an environmental report prepared by the licensee, including sensitivities on the release elevation (with a change from ground level to the top of containment [modeled as 70 m in that analysis]). This change in release elevation resulted in decreased deposition close in, but a slightly (10 percent) higher population dose within 50 miles, as a result of the relatively less depleted plume. A sensitivity on plume heat (resulting in buoyant plume rise) resulted in similar effects, suggesting that some MACCS results could be somewhat sensitive to the assumed plume release height characteristics.

Table 3.1-10: Description of release points from MELCOR modeling

Description	Location	MELCOR Release Paths	Effective Building Dimensions	Physical Elevation of Release (m)
SG 1 SRV tailpipe	South Main Steam Valve Room Roof	372	Containment, 45 m x 55 m	13
SG 1 SRV tailpipe	South Main Steam Valve Room Roof	373	Containment, 45 m x 55 m	13
SG 1 SRV tailpipe	South Main Steam Valve Room Roof	374	Containment, 45 m x 55 m	13
SG 1 SRV tailpipe	South Main Steam Valve Room Roof	375	Containment, 45 m x 55 m	13
SG 1 lowest setpoint SRV tailpipe	South Main Steam Valve Room Roof	376	Containment, 45 m x 55 m	13
SG 1 ARV tailpipe	South Main Steam Valve Room Roof	377	Containment, 45 m x 55 m	13
SG 1 PORV leakage	South Main Steam Valve Room Roof	379	Containment, 45 m x 55 m	13
SG 2 SRV tailpipe	North Main Steam Valve Room Roof	472	Containment, 45 m x 55 m	13
SG 2 SRV tailpipe	North Main Steam Valve Room Roof	473	Containment, 45 m x 55 m	13
SG 2 SRV tailpipe	North Main Steam Valve Room Roof	474	Containment, 45 m x 55 m	13
SG 2 SRV tailpipe	North Main Steam Valve Room Roof	475	Containment, 45 m x 55 m	13
SG 2 lowest setpoint SRV tailpipe	North Main Steam Valve Room Roof	476	Containment, 45 m x 55 m	13
SG 2 ARV tailpipe	North Main Steam Valve Room Roof	477	Containment, 45 m x 55 m	13
SG 2 PORV leakage	North Main Steam Valve Room Roof	479	Containment, 45 m x 55 m	13
SG 3 SRV tailpipe	North Main Steam Valve Room Roof	572	Containment, 45 m x 55 m	13
SG 3 SRV tailpipe	North Main Steam Valve Room Roof	573	Containment, 45 m x 55 m	13
SG 3 SRV tailpipe	North Main Steam Valve Room Roof	574	Containment, 45 m x 55 m	13
SG 3 SRV tailpipe	North Main Steam Valve Room Roof	575	Containment, 45 m x 55 m	13
SG 3 lowest setpoint SRV tailpipe	North Main Steam Valve Room Roof	576	Containment, 45 m x 55 m	13
SG 3 ARV tailpipe	North Main Steam Valve Room Roof	577	Containment, 45 m x 55 m	13
SG 3 PORV leakage	North Main Steam Valve Room Roof	579	Containment, 45 m x 55 m	13
SG 4 SRV tailpipe	South Main Steam Valve Room Roof	672	Containment, 45 m x 55 m	13
SG 4 SRV tailpipe	South Main Steam Valve Room Roof	673	Containment, 45 m x 55 m	13
SG 4 SRV tailpipe	South Main Steam Valve Room Roof	674	Containment, 45 m x 55 m	13

Table 3.1-10: Description of release points from MELCOR modeling (continued)

Description	Location	MELCOR Release Paths	Effective Building Dimensions	Physical Elevation of Release (m)
SG 4 SRV tailpipe	South Main Steam Valve Room Roof	675	Containment, 45 m x 55 m	13
SG 4 lowest setpoint SRV tailpipe	South Main Steam Valve Room Roof	676	Containment, 45 m x 55 m	13
SR 4 ARV tailpipe	South Main Steam Valve Room Roof	677	Containment, 45 m x 55 m	13
SG 4 PORV leakage	South Main Steam Valve Room Roof	679	Containment, 45 m x 55 m	13
Piping penetration area filtration and exhaust system exhaust (through the plant stack)	Plant Stack	027	Containment, 45 m x 55 m	13[8]
Normal Containment Leakage	Containment*	820	Containment, 45 m x 55 m	42
Normal Containment Leakage	Containment*	821	Containment, 45 m x 55 m	25
Normal Containment Leakage	Containment*	824	Containment, 45 m x 55 m	25[9]
Containment Overpressure	Containment***	841	Containment, 45 m x 55 m	0
Containment Overpressure	Containment***	842	Containment, 45 m x 55 m	0
Normal Aux Building Leakage	Aux Building*	997	Aux Building**, 38 m x 14 m	0
Normal Aux Building Leakage	Aux Building*	998	Aux Building**, 38 m x 14 m	6

[8] After completion of the analysis, it was discovered that the release elevation was in error. The corrected physical elevation would be 55 m above grade. However, FL027 is a negligible contributor to all release categories except for release category V (STG 5), where it is 10-14 percent of total release category frequency, and release category LCF-SC (STG 2R2), where it is 20-25 percent of total release category frequency. Because these source terms are among the smallest of those analyzed, and because the effect of turbulent wake effects would introduce additional uncertainties in release height regardless of the physical release elevation, this is not expected to be a significant source of error in the overall results.

[9] After completion of the analysis, it was discovered that the release elevation from MELCOR was in error. The corrected physical elevation would be 16 m above grade. This is not expected to be a significant source of error in the final results because releases through normal containment leakage flow paths are typically small in relation to other flow paths, and because the effect of turbulent wake effects would introduce additional uncertainties in release height regardless of the physical release elevation.

Table 3.1-10: Description of release points from MELCOR modeling (continued)

Description	Location	MELCOR Release Paths	Effective Building Dimensions	Physical Elevation of Release (m)
Tendon gallery access shafts (2 of 3)	Aux Building*	844	Aux Building**, 38 m x 14 m	0
Aux Building Overpressure	Aux Building*	995	Aux Building**, 38 m x 14 m	11

Source: adapted from Table 2-27 in (NRC 2019)

** Precise failure location not specified – source can be distributed over the surface area of the structure or located at any point on the structure*

*** Dimensions of auxiliary building from the site environmental report*

**** Note that the location is quite uncertain. Releases could occur from multiple locations with elevations ranging from 0-18 m above grade from a variety of structures.*

3.1.2.7 *Plume Segment Definitions*

For long duration releases, when both the characteristics of release and the meteorological conditions may vary, MACCS has the capability to subdivide the release into individual homogeneous plume segments. MACCS currently allows for up to 500 individual plume segments to be defined. The preprocessor code MelMACCS is used to read the MELCOR output files and create plume segments in a format readable by MACCS.

The segmentation of the MELCOR outputs by MELMACCS is defined by two considerations: whether a particular flow path or individual plume segment contains a sufficient amount of released material to affect the final results, and the measurement interval for the weather observations. Two parameters, which can be defined by the user, control which of the MELCOR paths is displayed and which plume segments are considered. The first of these causes flow paths to be evaluated when more than 0.001 (0.1 percent) of the total release of any chemical group occurs through a flow path. This enhances computational efficiency by excluding release paths without significant contributions to the total release (i.e., those that contribute less than 0.1 percent of the total release for each chemical class). The second parameter causes a plume segment to be evaluated if any of the chemical groups in that segment contribute a user defined portion of the total release of that chemical group. No mass fraction threshold was used for the plume segments, and therefore all of the release from the modeled flow paths are modeled in MACCS. While there may be multiple modeled release flow paths for any given source term, typically one or two flow paths contain the vast majority of the release during an observable time period (which includes the revaporization of the Te and I chemical groups, if such an event occurs). The major flow path(s) and this time period are identified from the cumulative release magnitudes. For these release paths, the release was divided into approximately 1-hour plume segments to be consistent with the available hourly meteorological data. If a 1-hour timestep was not available on the MELCOR plot file for these paths, the shortest time period greater than 1 hour was used. Releases from any minor flow paths, or for the revaporization tail of the release from the major flow path(s), may occur over long time periods but do not contain substantial release magnitudes. Because of their relatively small release magnitudes, it is assumed to be unnecessary to divide these portions of the release into smaller plume segments. These long plume segments are checked to make sure they do not contribute a larger release magnitude than the plume segments from the major portion of release, as verification that use of long plume durations does not substantially affect the results. These plume segments are either modeled as is, or if necessary, their release duration is manually adjusted to 24 hours after running MelMACCS, because MACCS does not allow plume segment durations longer than 24 hours.

The Gaussian plume segment model in MACCS requires information for each plume segment on the time at which the segment begins to release (PDELAY) and the duration of the plume segment (PLUDUR); and the amount of material released, defined as the fraction of each chemical group that is released (RELFRC). In addition, the MACCS atmospheric dispersion models, discussed in more detail in Section 3.3.1.2 of this document, require information related to the initial dimensions of the plume, since the downwind transport of the plume is affected by the initial location of the release, the initial rise of the plume due to buoyancy effects, and

spreading of the plume due to turbulence from building wakes. The plume rise models require information on the heat content (PLHEAT) or gas density (PLMDEN) and plume mass flow rate (PLMFLA) to compute the buoyancy flux, as described in Section 3.3.3. These parameters are computed by MELCOR and are parsed by MelMACCS to define the plume segment.

When an analysis is designed using weather bin sampling, MACCS uses a parameter known as MAXRIS to specify which plume segment is to be considered risk dominant. Release of the risk-dominant plume segment always begins at the selected meteorological start time of the weather sequence, and ensures that the weather sampling algorithms (see Section 3.2.2) are based on consideration of the most significant release. The selection of this plume segment is usually based on its potential for causing early fatalities. In the L3PRA project, MAXRIS was generally assigned to be the point at which a significant increase in the release rate occurred. Although the base case uses all available weather data and the MAXRIS variable is therefore expected to be less significant, it is still defined to facilitate potential sensitivity cases involving a subset of available weather data.

A summary of the MELCOR source terms, including the number of plume segments and value of MAXRIS for each case, is given in Table 3.1-11. For the source terms that (NRC 2019) identified should be truncated, the truncation was accomplished within MELMACCS by truncating the release at the specified time. The complete plume segment definition for all cases, including the values for the release pathway, plume heat, density, flow rate, and release fraction for each plume segment, is included in Appendix A under Table A.1a.

Table 3.1-11: Summary of MACCS source terms

Release Category	MELCOR Modeling Case	NUMREL	MAXRIS	GE (hr)	Onset of Release (hr)	Onset of Major Release (hr)	Cs Release Fraction	I Release Fraction
ICF-BURN	1A2	115	9	3.0	16	28	3.2E-02	4.3E-02
ICF-BURN-SC	1A2_TR28	6	1	3.0	16	28	5.9E-05	6.9E-05
LCF	1B	179	24	3.0	3.6	55	9.9E-03	1.2E-02
ECF	2A	222	5	8.0	13	22	1.6E-01	1.5E-01
NOCF	2R1	199	16	8.0	13	Never	7.4E-05	8.5E-05
LCF-SC	2R2	131	59	8.0	13	128	1.7E-03	6.0E-04
ISGTR	3A2	292	1	8.0	10	11	9.2E-02	2.3E-01
V	5	101	4	7.5	9.4	10	6.4E-04	1.1E-03
V-F-SC	5B	110	1	1.25	2.7	3.2	9.2E-02	1.2E-01
V-F	5D	86	6	1.25	2.7	3.2	1.3E-01	1.4E-01
BMT	6	213	5	13	15	Never	5.4E-05	6.4E-05
CIF	7	167	4	3.0	16	21	3.4E-02	4.2E-02
CIF-SC	7A	179	4	3.0	16	18	2.5E-02	3.3E-02
SGTR-C	8	152	2	47	49	52	1.1E-02	1.2E-02
SGTR-O	8B	173	2	47	49	51	2.5E-01	3.4E-01
SGTR-O-SC	8BR1	20	3	47	49	51	1.0E-02	9.1E-03

3.1.3 MACCS Radionuclide Release Input Parameter Summary

A summary of the MACCS input parameters for radionuclide release characterization is provided in Table 3.1-12.

Table 3.1-12: Summary of MACCS inputs related to radionuclide release characterization

MACCS Input Parameters Variable	Description	Value	Source
ATNAM1	Title Describing the ATMOS Assumptions		
ATNAM2	Title Describing the Source Term		
MSMODL	Multisource Model Flag	FALSE	
NUMISO	Number of Radionuclides	69	Section 3.1.2.2
NUCNAM	Radionuclide Names	Table 3.1-5	
NUMSTB	Number of Pseudostable Radionuclides	16	
NAMSTB	List of Pseudostable Nuclides	Table 3.1-6	
CORINV	Isotopic Inventory at Time of Reactor Shutdown (Bq)	Table 3.1-7	
CORSCA	Linear Scaling Factor on Core Inventory	1.0	
APLFRC	Method of Applying Release Fraction	PARENT	
MAXGRP	Number of Radionuclide Groups	9	Section 3.1.2.3
GRPNAM	Names of the Radionuclide Groups	Table 3.1-8	
IGROUP	Definition of Radionuclide Group Numbers	Table 3.1-8	
NPSGRP	Number of Particle-Size Groups	10	Section 3.1.2.4
PSDIST	Particle-Size Distribution by Group	Table A.1b	
BUILDH	Building Height (m)	Table 3.3-2[2]	Section 3.1.2.5
PLHITE	Plume Release Height (m)	Table 3.3-2[2]	
NUMREL	Number of Released Plume Segments	Table 3.1-11	Section 3.1.2.6 Plume segment parameter values from MELCOR as segmented by MELMACCS based on duration and threshold definitions.
MAXRIS	Selection of Risk-Dominant Plume Segment	Table 3.1-11	
REFTIM	Plume Reference Time Point	0 for first 0.5 for subsequent	
PLHEAT[1]	Plume Heat Contents (W)	Table A.1a	
PLMDEN	Plume Mass Density (kg/m^3)	Table A.1a	
PLMFLA	Plume Mass Flow Rate (kg/s)	Table A.1a	
PDELAY	Plume Release Times (sec)	Table A.1a	
PLUDUR	Plume Segment Durations (sec)	Table A.1a	

Table 3.1-12: Summary of MACCS inputs related to radionuclide release characterization (continued)

MACCS Input Parameters Variable	Description	Value	Source
RELFRC	Release Fractions of the Source Term	Table A.1a	

1 Value is reported in table but not used; plume mass density and flow rate are used to compute buoyancy flux instead.
2 Based on information in Table 3.1-10

3.1.4 Identification and Discussion of Uncertainties Related to Radionuclide Release Characterization

There are a number of sources of uncertainty in the calculation that were identified by project staff. These are listed in Table 3.1-13 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.1-14 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.1-13. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS.

Of all the uncertainties identified in Table 3.1-13, the uncertainties in accident progression or source term modeling that would propagate into the source terms used in the MACCS calculations are judged to be the most significant. The significance of these uncertainties is dependent upon the extent to which they change the source term characteristics, particularly in terms of release timing and magnitude. This is related to the fact that MELCOR source terms selected to represent release categories have to represent a spectrum of potential accidents from the Level 1 and Level 2 PRA, each of which may have different consequences. The existing source terms cover a wide range of release magnitudes and timings, such that alternate source terms are expected to be reasonably within the envelope of the existing source terms. However, the relative frequency of different source terms with different release timings and magnitudes, and thus the integrated risk results, could change if there were significant differences in the relative frequency of the different scenarios.

The core inventory used in the calculation is a potential source of uncertainty, in that the point in the cycle assumed for the calculation can affect the inventory of fission products that can accumulate over the lifetime of the core. The current calculations are based on middle-of-cycle inventories. Inventories for beginning of cycle and end of cycle are also available and could be used for sensitivity analyses. The core inventory associated with different times in the operating cycle would also give rise to differences in chemical inventories and decay heats, which would affect the accident progression characteristics. However, treatment of that aspect of inventory would require an integrated Level 2/Level 3 sensitivity analysis, which is beyond the scope of this analysis. Because this is a joint Level 2/Level 3 uncertainty, it is also identified in the summary of uncertainties for the Level 2 PRA modeling (Appendix C of [NRC 2019]).

Table 3.1-13: Uncertainties related to radionuclide release characterization

3.1.2.1 Transition from Level 2 to Level 3	Uncertainties in accident progression or source term modeling would propagate into the source terms used in the MACCS calculations. The significance of these uncertainties is dependent upon the extent to which they change the source term characteristics, particularly in terms of release timing and magnitude.
	MELCOR source terms selected to represent release categories have to represent a spectrum of potential accidents from the Level 1 and Level 2 PRA, each of which may have different consequences. The significance of these uncertainties depends on the relative likelihood of different accident progression scenarios.
3.1.2.3 Identification of Radionuclides and Development of Initial Radionuclide Inventory	Although the core inventory contains hundreds of different isotopes, only a limited subset of isotopes is explicitly modeled. This is not expected to be a significant source of uncertainty because the nuclides have been selected via a systematic process focused on identifying nuclides expected to be important to risk.
	Uncertainties in core inventory modeling from ORIGEN/SCALE would propagate forward into core inventory estimation. This is not expected to be a significant source of uncertainty because the core inventory is not expected to be significantly different from that modeled, given the assumptions regarding burnup and time in cycle.
	The choice of when in the operating cycle is represented in the inventory will lead to uncertainty in core inventories representing the temporal variability of core inventory. For example, the inventory of Cs-134 and Cs-137, which are important to long-term doses, can vary significantly from the beginning of the cycle to the end of the cycle. This could be significant for some types of consequences, particularly those that depend upon longer lived radionuclides that may accumulate over the operating cycle.
3.1.2.4 Chemical Class Assignments	Binning of elements into chemical classes is a source of uncertainty, as the chemical and physical form of each isotope may differ from the characteristics of the chemical class. This could be a significant source of uncertainty if the characteristics of transport or dosimetric characteristics of isotopes with multiple chemical forms vary significantly.
3.1.2.5 Aerosol Characteristics	The distribution of aerosol sizes may change over the course of the release, but must be represented as a single value for all plume segments. This is not expected to be a significant source of uncertainty because later releases are expected to have a relatively stable aerosol size distribution. Releases that include both a relatively large early and late component may exhibit more significant differences in the evolution of the aerosol size distribution.

Table 3.1-13: Uncertainties related to radionuclide release characterization (continued)

3.1.2.5 Aerosol Characteristics	Aerosol transformations that may alter the size distribution (e.g., agglomeration/accumulation/deposition, iodine chemical form transformations) during transport in the environment are not explicitly treated in the modeling. This could be a significant source of uncertainty at long distances for early release with aerosol size distributions skewed toward the smaller end or conversion of iodine into less reactive forms.
	Uncertainty is introduced by the segmentation of a continuous aerosol size distribution into discrete bins. This is not expected to be a significant source of uncertainty if a reasonably large number of bins are defined, such that no single bin contains the majority of the release.
3.1.2.6 Plume Release Path Characterization	The exact release location of releases associated with structural failure is unknown. It is expected that the impact of this uncertainty would be limited to the near field before significant vertical mixing had occurred, as mixing within the boundary layer would eventually reduce the sensitivity of model results to alternate release heights (provided that significant depletion does not occur before the plume is fully mixed). The net effect of this uncertainty is related to plume rise effects, which have been examined in past SAMA analyses as a sensitivity. This could be a significant source of uncertainty for near-field effects, where ground-level concentrations could be sensitive to the plume size and height, but is not expected to be significant further downwind once the plume has grown in the vertical and crosswind directions.
	The crosswind building dimensions will vary depending upon the wind direction, which is not explicitly modeled.
3.1.2.7 Plume Segment Definitions	Uncertainty is introduced by the segmentation of a continuous release into discrete plume segments. This is not expected to be a major source of uncertainty, as this plume segments are generally divided into intervals consistent with the meteorological observation interval. Only very small releases are characterized by long plume segments.

Table 3.1-14: Potential sensitivity analyses to address uncertainties related to radionuclide release characterization

ID	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
RE_1	Examine the impact of using a larger subset of radionuclides	Alternate isotope lists (i.e., from earlier studies or developed to include a wider set of nuclides), coupled with the more expansive set of dose factors available in the newer dose coefficient libraries	Limited change in estimated doses, particularly for long-term dose contributors	Alternate input decks
RE_2	Examine effect of time of accident relative to refueling cycle	Alternate core inventories (i.e., the inventory from L3PRA project calculations performed for BOC or EOC)	Consequences expected to vary with burnup	Cyclic file set
RE_3	Propagation of uncertainty from L2 analysis (i.e, of uncertainty introduced by use of only a subset of available source terms)	All 37 candidate source terms – all other MACCS parameters set to reference/base-case values	Mean value of integrated risk not expected to vary significantly with source terms selected	Alternate input decks
RE_4	Propagation of key uncertainty from L2 analyses (i.e., accident truncation time)	Alternate source terms representing release truncation at 36 hours after SAMG entry	Most consequences expected to be reduced with truncated source terms – consequences affected by warning time may be unaffected or less affected	Alternate input decks
RE_5	Examine how results change depending upon the number of aerosol size bins.	Use of a single aerosol deposition velocity bin representing a net effective deposition velocity	Changes in the deposition behavior with distance – consequences may be higher or lower depending on figure of merit and distance range under consideration	Alternate input deck

Table 3.1-14: Potential sensitivity analyses to address uncertainties related to radionuclide release characterization (continued)

ID	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
RE_6	Examine importance of building wake effects associated with the release location	The effect of this could be examined by performing sensitivity analyses to vary initial plume size, building dimensions, and release height.	It is expected that the impact of this uncertainty would be limited to the near field when the plume dimensions are comparable to the size of the building wake.	Cyclic file sets
RE_7	Examine impact of plume discretization timestep	Use of alternate (coarser or finer) plume segment intervals to examine how results may change	Staff experience with limited sensitivity analyses to evaluate the effect of plume segmentation suggest that this is most important for estimating early fatality risks from large releases.	Alternate input deck

3.2 <u>Meteorological Data (ME)</u>

3.2.1 Assumptions and Known Limitations

- Hourly data for a single year is used for the site (8,760 data points for each year). The variability within a single year of weather data (intra-annual variability) is assumed to be sufficient to capture the variability across multiple years of weather data (i.e., inter-annual variability).
- Missing data is bridged over using hourly records before and after by employing, “Procedures for Substituting Values for Missing National Weather Service Meteorological Data for Use in Regulatory Air Quality Models” (Atkinson and Lee 1992), consistent with the method used in SOARCA.
- Atmospheric stability categories are classified using vertical temperature difference, consistent with SOARCA. This is assumed to be an adequate representation of atmospheric stability.
- Consistent with WASH-1400, depletion by rainfall using boundary weather settings should not be implemented closer than distances of about 500 miles, consistent with an atmospheric aerosol residence time of several days. Since the project is not reporting results at greater than 100 miles, boundary weather is therefore not modeled.
- The use of the simple flat terrain model assumed in MACCS is considered reasonable for this site, because of the limited topographic relief.
- The use of the 10 m elevation wind speed as measured at the site is assumed to adequately represent wind speeds at higher elevations or longer distances from the site.

3.2.2 Technical Discussion

Atmospheric transport modeling for MACCS requires data on the wind speed, wind direction, stability class, mixing layer height, and rainfall rate during plume transport. MACCS has several options for treatment of meteorological data, which include the ability to directly input weather data (either constant weather conditions for the entire simulation or 120 hours of specified weather data), or the ability to sample weather data from an external input file. Sampling options include the ability to specify a particular time for the start of the release, to perform sampling of data from meteorological bins defined by the user, or to randomly sample from each day of the weather file. Site-specific data was used to construct weather files, and these files were sampled using the bin sampling technique. In these base case analyses, all hourly meteorological data (8760 observations) were used.

3.2.2.1 *Selection of Data*

The project obtained 5 years (1998-2002) of meteorological data from the site . The staff also considered 8 years of mixing height data (1984-1991) from two regional NWS upper air stations. Extensive information on the meteorological monitoring program from which the site meteorological data was obtained from licensee documentation submitted to the NRC. The NRC staff verified a joint data recovery rate in the 90th percentile, which is in accordance with Regulatory Guide 1.23 (NRC 2007a), for the wind speed, wind direction, and atmospheric

stability parameters. Since meteorological data used in MACCS are assumed to be taken at a 10-m reference level, development of the weather file focused on the lower (10 m) measurement level data. The data recovery statistics, based on initial processing of the meteorological data, are shown in Table 3.2-1, and a summary of the wind speed and precipitation statistics from the 5 years of data is shown in Table 3.2-2. Based on these data, the 1998 dataset was selected for the development of the meteorological file on the following basis:

- The 2002 dataset was eliminated due to the low rainfall recovery rate
- The 2001 dataset was eliminated as it had a lower data recovery rate than any of the remaining years
- The 1998 dataset had the highest wind direction, wind speed, and rainfall recovery rate, but the 1999 dataset had the highest overall recovery rate due to a lower stability class recovery rate in the 1998 data.

Based on this evaluation, the staff could have chosen either the 1998 or the 1999 dataset. Because of the importance of precipitation as a scavenger of airborne radioactivity (and consequent deposition), staff initially considered that the precipitation record is an important meteorological variable to consider when selecting a representative dataset. The 1998 weather dataset was chosen based on the total precipitation. The 5-year period (1998 through 2002) was an abnormally dry period in the region. Within this period, the total annual rainfall (40.3 inches) from the 1998 data set was the closest to the 30-year average annual rainfalls, which range from 44 to 52 inches, measured at nearby weather stations. Similarly, the 1998 dataset showed 97 days of measurable rainfall, which is lower than, but consistent with, the value of 109 days measured at a nearby NWS station. Other aspects of precipitation data (i.e., total hours with precipitation, total days with precipitation, etc.) could also have been chosen. Specific aspects of the documentation of the data are discussed below.

<u>Source of data (including reasons for selection)</u>: Five years of meteorological data were selected for use. Based on the extensive documentation of the meteorological measurements program in the environmental report, and the fact that this information was judged acceptable for use by NRC staff, staff concluded that this information is sufficient for use in the L3PRA project. The site also provided 10 months of site weather data (9/1/2012 to 7/15/2013) for use in the L3PRA project. However, because this data spanned less than 1 year and appeared to have periods of missing data, the project staff opted to use the 1998-2002 dataset, as it spanned a much longer period, generally had a very high data recovery rate, had already been reviewed for quality, and was formatted according to Regulatory Guide 1.23 (NRC 2007a) guidelines.

<u>Quality assessment and extent of conformance with ANSI/ANS-3.11-2010 and Regulatory Guide 1.23, Revision 1</u>: The environmental report states that the current onsite meteorological measurements program conforms to the requirements of 10 CFR 50.47 and the guidance criteria set forth in:

- Functional Criteria for Emergency Response Facilities, Final Report, 1981 (NUREG-0696)
- Clarification of TMI Plan Requirements, 1980 (NUREG-0737)

- FEMA-REP-1, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, Revision 1, Appendix 2, 1996, (NUREG-0654)
- Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors, Revision 1, 1977
- Regulatory Guide 1.21, Measuring, Evaluating, and Reporting Radioactivity in Solid Waste and Releases of Radioactive Materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants, Revision 1, 1974
- Regulatory Guide 1.23, Meteorological Programs in Support of Nuclear Power Plants, Proposed Revision 1, 1980
- American National Standards for Determining Meteorological Information at Nuclear Facilities,1984 (ANSI/ANS 2.5) – system accuracy conforms to ANSI/ANS 2.5

In its review of the environmental report, the NRC staff concluded that the system provides adequate data to represent onsite meteorological conditions as required by 10 CFR 100.20 and 10 CFR 100.21. The onsite system was also found to provide an acceptable basis for making estimates of atmospheric dispersion for design-basis accident and routine releases from the plant to meet the requirements of 10 CFR Part 20, 10 CFR 50.34, and 10 CFR Part 50, Appendix I. Based on this conclusion by the NRC staff, project staff concludes that the intent of assessing the extent of conformance with ASME standards and Regulatory Guide 1.23 (NRC 2007a) is met and that the data is of sufficient quality for use in the L3PRA project. Although the staff did not explicitly use the methods identified in NUREG-0917 (NRC 1982b) (specifically, the QA subroutine as specified in Section 8), as identified in the TAAP assumptions, the fields that are examined in that analysis were inspected during the importation of the data.

<u>Levels of sensors</u>: As documented in licensee submittals to the NRC, the primary meteorological tower is a 197-ft (60-m) tower with permanent sensors located at the 33-ft (10-m) level and the 197-ft (60-m) level. Wind speed, wind direction, and temperature are measured at the 60-m elevation. Wind speed, wind direction, ambient temperature, and dew point temperature are measured at the 10-m elevation. The differential temperature is calculated as the difference between the 10-m temperature and 60-m temperature. Precipitation is monitored at ground level. The backup meteorological tower is a 148-ft (45-m) tower in the same clearing as the primary tower. Sensors at the 10-m elevation monitor wind speed, wind direction, and ambient temperature. The 10-m elevation is the standard elevation level used for meteorological information in the MACCS code.

<u>Exposure of tower</u>: The exposure of the instruments is discussed in licensee submittals to the NRC. The instruments are located away from structures or terrain features that could affect the meteorological observations. The area around the towers is mown grass and kept clear of trees or other obstructions. The potential for topographic features that could affect the meteorological observations is also discussed in licensee submittals to the NRC. The terrain surrounding the site is flat to gently rolling. The extent to which significant topographic effects due to the location of the site adjacent to the broad river valley could affect the meteorological

observations, such as valley or mountain flows, land or sea breezes, or the development of thermal internal boundary layers due to significant variations in land cover, could affect meteorological observations has not been independently evaluated in this analysis. However, as noted above, NRC staff had previously concluded that the system provides an acceptable basis for making estimates of atmospheric dispersion for design-basis accident and routine releases.

Calibration records: Instrument calibration is discussed in licensee submittals to the NRC, where it is stated that the meteorological monitoring system is calibrated at least semi-annually at both the primary and backup towers, and that inspection, service, and maintenance are performed according to the instrument manuals.

Period of record: The period of record covers the 5-year period from 1998-2002.

Percent data recovery: Data recovery for all years was determined to be greater than 90 percent. Detailed information on data recovery is discussed above and summarized in Table 3.2-1.

Table 3.2-1: Meteorological data recovery from 1998-2002

Year	Wind Direction	Wind Speed	Stability (Delta-T)	Rainfall	Average
Lower Measurement Level					
1998	99.1%	98.9%	96.6%	99.5%	98.5%
1999	98.9%	98.4%	98.6%	99.3%	98.8%
2000	98.7%	97.4%	97.4%	99.4%	98.2%
2001	95.3%	95.1%	94.9%	96.3%	95.4%
2002	96.4%	97.0%	99.3%	78.8%	92.9%
Upper Measurement Level					
1998	88.2%	98.3%	96.6%	99.5%	95.7%
1999	93.3%	97.9%	98.6%	99.3%	97.3%
2000	96.9%	97.8%	97.4%	99.4%	97.9%
2001	95.3%	95.2%	94.9%	96.3%	95.4%
2002	97.6%	96.7%	99.3%	78.8%	93.1%

Table 3.2-2: Wind speed and precipitation summary from 1998-2002

Year	Average 10 m Wind Speed (m/s)	Total Precip (in)	Days with Precip	Hours of Precip
1998	2.3	40.3	97	328
1999	2.3	33.1	97	463
2000	2.4	29.2	84	305
2001	2.5	34.2	79	228
2002	2.6	34.8	73	275

3.2.2.2 *MACCS Implementation*

MACCS requires data for wind speed, wind direction (defined in terms of compass sector the wind is blowing toward – 64 compass sectors were used in the project), atmospheric stability (defined using the classes in Regulatory Guide 1.23 (NRC 2007a) using values of 1–6 to represent stability classes A–F/G), hourly precipitation, and diurnal (morning and afternoon) seasonal mixing heights. The format of the MACCS site meteorological file is described in Appendix B.1 of (Chanin et al. 1990), and in Appendix A.1 of (Chanin and Young 1998a).

An Excel 2007 spreadsheet was used to convert the input data files to a MACCS site meteorological file. The project used one year of hourly meteorological data (8,760 data points for each meteorological parameter). Wind speed, wind direction, and precipitation were taken directly from the reported weather data, and temperature measurements at two elevations on the site meteorological tower provided stability class data following the procedure recommended in Regulatory Guide 1.23 (NRC 2007a). Although the MACCS input file can accept the seven stability classes defined in Regulatory Guide 1.23, the last two stability classes (F and G) are combined by the code, with values of 7 being changed to values of 6. The detailed procedure used was as follows:

1) The hourly observation data for each year was imported into an Excel 2007 worksheet
2) A worksheet was created to extract the data into MACCS formatted columns:
   a. Time stamps were converted from monitoring data time format (i.e., 0 hr to 23 hr) to MACCS format (i.e., 1 hr to 24 hr).
   b. Wind speed at the selected height (10 m for the L3PRA project) was converted into units of tenths of meters per second;
   c. Wind direction at the selected height was converted from angular measurements into MACCS compass sectors. The Regulatory Guide 1.23 data format provides wind direction in terms of compass angle FROM which the wind is blowing. The MACCS file requires wind direction in terms of the sector TOWARDS which the wind is blowing. The sectors were defined such that Sector 1 (north) was centered on zero degrees, and the sector width was defined by 360° divided by the number of sectors (64 in this analysis, or 5.625° per sector), that is,

Sector	Measured Wind Direction (From)
1	180.000° (177.1875°-182.8125°)
2	185.625° (182.8125°-188.4375)
3	191.250° (188.4375°-194.0625°)
4	196.875° (194.0625°-199.6875°)
…	…

   d. Stability class was determined based on the lapse rate (temperature gradient calculated from the difference between the upper and lower measurement level readings and the distance between the measurement levels) and the procedure based on Regulatory Guide 1.23, shown in Table 3.2-3.

e. Precipitation was taken from the hourly observations and converted to units of 100th of an inch per hour.

3) For missing data values, a procedure consistent with “Procedures for Substituting Values for Missing NWS [National Weather Service] Meteorological Data for Use in Regulatory Air Quality Models” (Atkinson and Lee 1992), was developed. Initial estimates of the values of the missing data were developed by assuming relatively persistent diurnal weather conditions prevailed over a period of several days before and after the missing measurement. The initial estimate was derived as the average of the values from the surrounding hourly measurement, together with the values for the corresponding 3 hours from the preceding 2 days and the following 2 days (i.e., average of the 14 observations at t±1, t± (24±1),and t± (48±1)). In the event of missing measurements within the first 2 days of the year, the values from the preceding 2 days are not available. In this case, only data for the surrounding hours and the following 2 days were used. A similar approach was followed if measurements were not available in the last 2 days of the year. This procedure ensured that a reasonably consistent estimate could be made provided that data were available for at least one hourly measurement at approximately the same time of day within a few days of the missing data, and avoided the use of a default value that would likely result in an artificially persistent condition with no meteorological variability.

- For the 1998 data, temperature data were unavailable for the upper measurement level from 16:00 on Jan 30 until 17:00 on February 4, and consequently the delta-T values could not be determined. Because of the length of the data gap, the algorithm was unable to generate replacement values for delta-T for the period from 17:00 on February 1 until 16:00 on February 2. For this case, a replacement value was generated by taking the midpoint between the synthesized stability class computed by the algorithm for the same hour of the previous and following day (i.e., the stability class 24 hours prior to the missing hourly estimate and the stability class 24 hours after the missing hourly estimate).

4) All proposed replacement values were then reviewed and adjusted (if necessary) by an NRC staff meteorologist based on a professional understanding of the typical meteorological conditions and variability at the site.

5) The data were read into a worksheet that was formatted according to the MACCS meteorological file requirements documented in Appendix A.1 of (Chanin and Young 1998a), which could then be saved as a text file.

Table 3.2-3: Regulatory Guide 1.23 stability class data lookup table

Stability	Alphabetic Classification	Numerical Classification	Lower bound dT/dZ (°C/100 m)	Upper bound dT/dZ (°C/100 m)
Extremely unstable	A	1		≤ -1.9
Moderately unstable	B	2	> -1.9	≤ -1.7
Slightly unstable	C	3	> -1.7	≤ -1.5
Neutral	D	4	> -1.5	≤ -0.5
Slightly stable	E	5	> -0.5	≤ 1.5
Moderately stable	F	6	> 1.5	≤ 4.0
Extremely stable	G	7	> 4.0	

In addition to hourly measurement data, the MACCS site meteorological file requires morning and afternoon mixing height data for four meteorological seasons as shown in Table 3.2-4, for a total of eight entries per year. Mixing height can be specified in MACCS to vary as a function of the season of the year and the time of day at which the release begins by setting the flag for mixing height (MAXHGT) to the value DAY_AND_NIGHT and defining the latitude and longitude of the site (used for computing the times of sunrise and sundown). The morning mixing height is the minimum mixing height used in the code, and the afternoon mixing height is the maximum mixing height. MACCS estimates the mixing height value by linear interpolation between the minimum and the maximum, based on the time of day. Mixing height data require upper air measurements which are only available at selected locations across the United States. The mixing height data used for this analysis came from the U.S. Environmental Protection Agency (EPA) Support Center for Regulatory Atmospheric Modeling (SCRAM) database[10] for the state in which the site is located.[11] The first of these two stations had data from 1984-1988 and 1991, and the second had data from 1989-1991. Although the first station was slightly more distant from the site (138 miles versus 105 miles), it was used because of a longer period of data and an elevation (140 ft above sea level) that was closer to that of the site (220 ft above sea level) than the alternate station (802 ft above sea level). The procedure used to generate mixing height data was as follows:

1) The yearly data files were extracted into an Excel spreadsheet following the fixed width field definitions described in http://www.epa.gov/ttn/scram/surface/mixfor.txt.
2) The mixing height values were reviewed by a staff meteorologist. Several values of the morning mixing height that appeared anomalous (e.g., an AM mixing height of 4,171 m on 9/15/1985, with no measured data in any other field) were eliminated from the dataset.

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[10] The EPA SCRAM Web site is http://www.epa.gov/scram001/mixingheightdata.htm.

[11] Although a station in another state was geographically the closest to the site, it was not considered representative of site meteorological conditions and was not selected for evaluation.

3) A pivot table was constructed to extract, for each month, the average morning and afternoon mixing height for either a given year or for all years from the daily observations. Although some data were missing from the dataset, averages were taken over the available data, because hourly mixing height estimates were not needed and the data recovery rate (97 percent) was judged to be sufficiently high that construction of replacement data was not necessary.

4) The seasonal average values for each year were then averaged to develop the MACCS input parameters. Consistent with MACCS, the meteorological seasons were defined as follows:

Winter	Spring	Summer	Autumn
December	March	June	September
January	April	July	October
February	May	August	November

The results of this process, in meters, are shown in Table 3.2-4.

Table 3.2-4: Summary of seasonal mixing height values (meters)

Year	Morning				Afternoon			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
1984	350	388	398	392	1101	1637	1692	1362
1985	401	320	382	450	1068	1529	1390	1085
1986	513	395	419	459	904	2016	2087	1376
1987	395	424	359	342	850	1687	1780	1216
1988	319	362	372	369	986	1643	1829	1180
1989	407	472	473	315	897	1312	1438	1260
1991	350	388	398	392	1101	1637	1692	1362
Average	398	394	400	388	967	1637	1703	1247

This procedure yielded an annual average morning mixing height of 394 m and an annual average afternoon mixing height of 1390 m. This is broadly consistent with the results (reproduced below in Figure 3.2-1) from (Holzworth 1972).

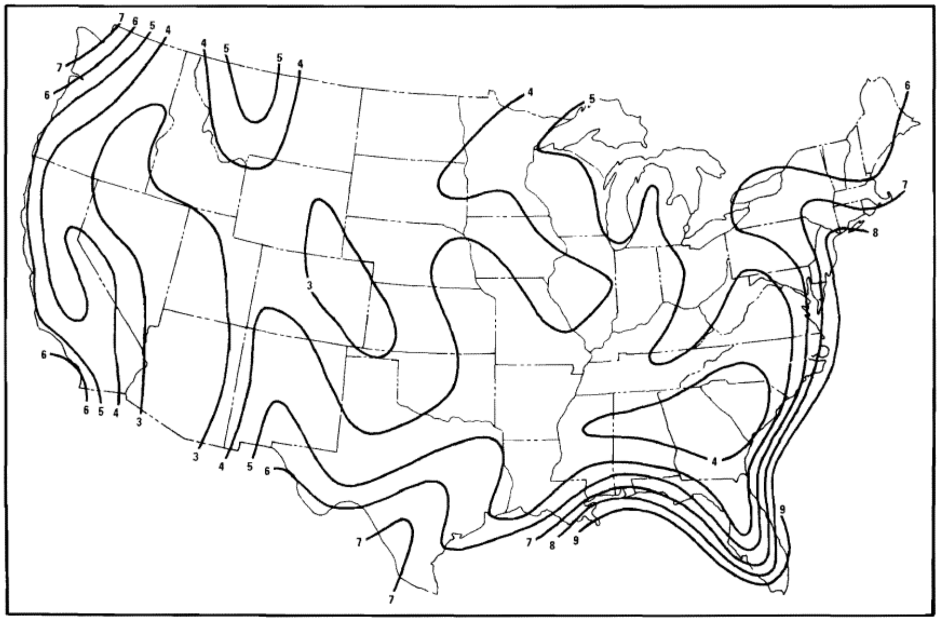

Figure 1. Isopleths (m x 10^2) of mean annual morning mixing heights (see Table B-1 for data).

Figure 3.2-1a: Mean annual morning mixing heights (100 m)
Source: reproduced from (Holzworth 1972)

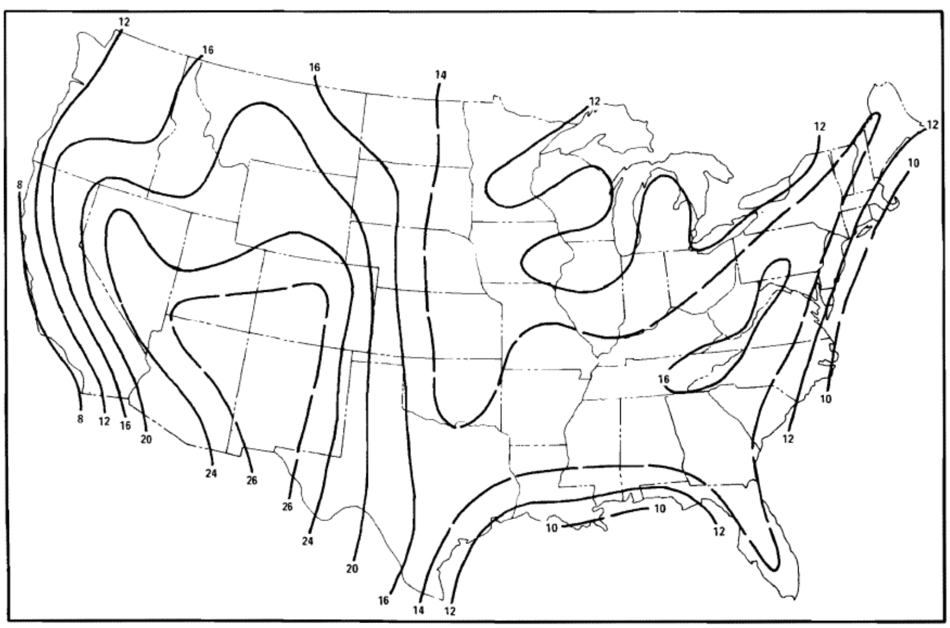

Figure 6. Isopleths (m x 10^2) of mean annual afternoon mixing heights (see Table B-1 for data).

Figure 3.2-1b: Mean Annual Afternoon Mixing Heights (100 m)
Source: reproduced from (Holzworth 1972)

Therefore, the mixing height data, in units of hundreds of meters, are provided in Table 3.2-5.

Table 3.2-5: Mixing height values for MACCS analyses (hundreds of meters)

Morning				Afternoon			
Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
4.0	3.9	4.0	3.9	9.7	16.4	17.0	12.5

The wind speed statistics for the 1998 dataset (Figure 3.2-2) show a most likely wind speed of 2-3 m/s. The average wind speed is 2.3 m/s, which is slightly lower than the 2.5 m/s average wind speed from 1998-2002 at the site and the 2.7 m/s annual average wind speed based on a 28-year period of record at the nearby NWS station.

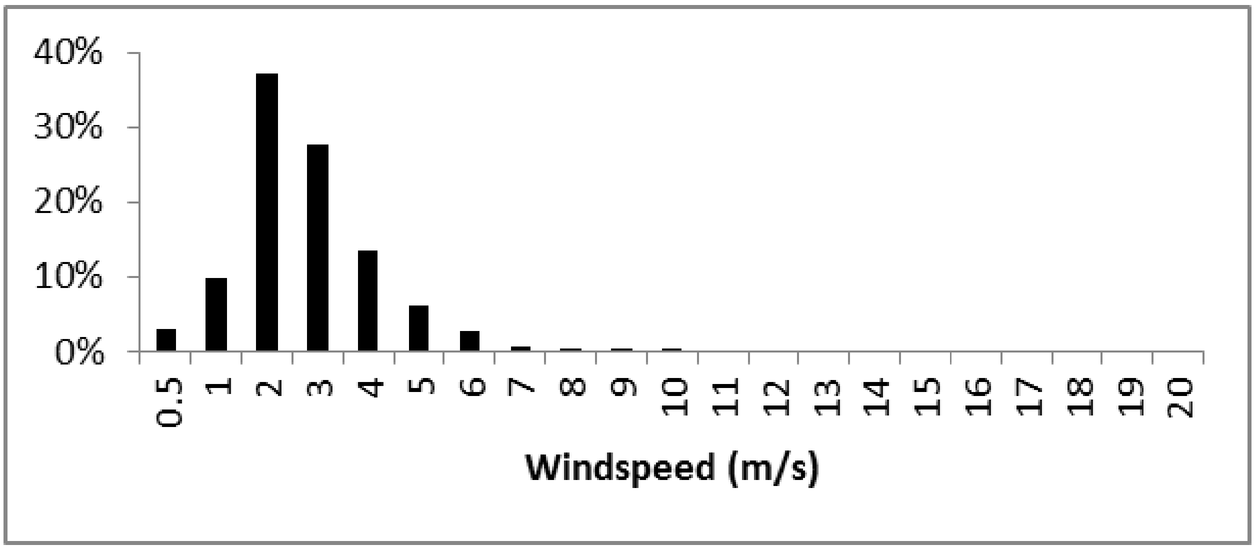

Figure 3.2-2: Wind speed distribution derived from 1998 dataset

The wind direction derived from the 1998 dataset is shown in Figure 3.2-3. This pattern is consistent with the annual 10 m wind rose shown in the site environmental report (note that Figure 3.2-3 follows the MACCS convention of showing the direction TOWARDS which the wind is blowing rather than the meteorological convention of showing the direction FROM which the wind is blowing).

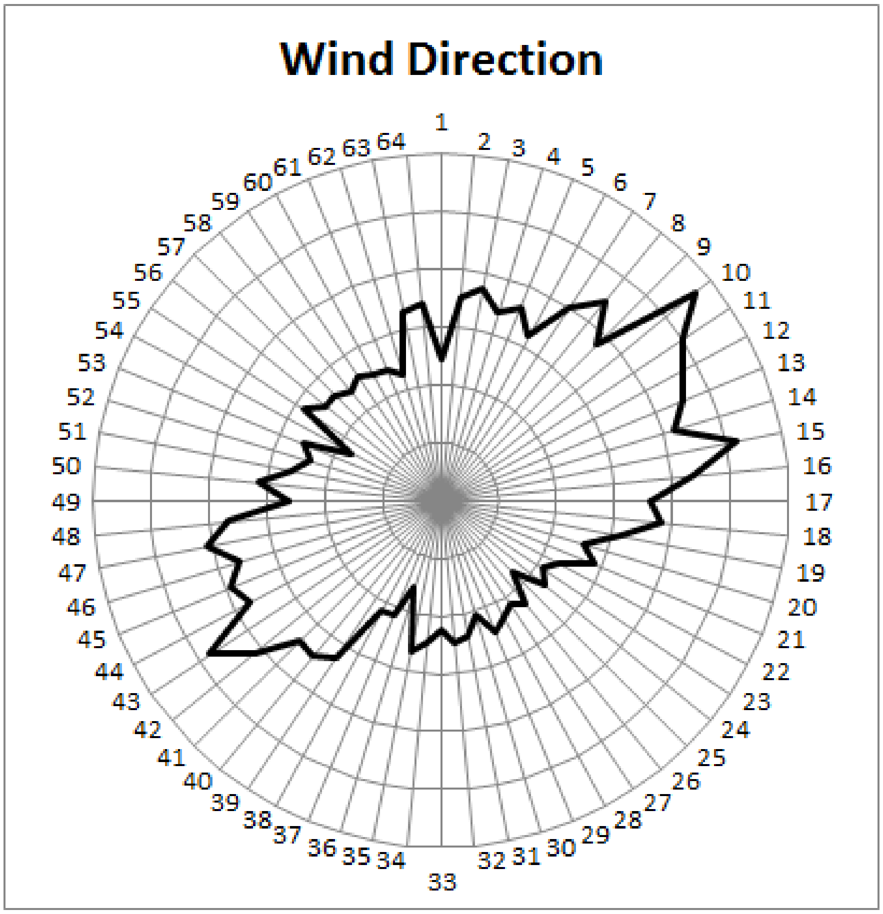

Figure 3.2-3: Wind direction derived from 1998 dataset

The staff evaluated the atmospheric stability of the 1998 dataset to determine whether the time of occurrence and duration of reported stability conditions were generally consistent with expected meteorological conditions (e.g., neutral and slightly stable conditions predominated during the year with stable and neutral conditions occurring at night and unstable and neutral conditions occurring during the day). Figure 3.2-4 shows the average[12] stability class by hour of day based on the 1998 dataset. This pattern is consistent with the expected pattern of stable night time conditions and unstable daytime conditions.

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[12] Note that averaging of the numerical stability indices is performed only to provide a relative indication of the typical diurnal change in stability and should not be used to determine an "average" stability class. The approach used in NUREG/CR-7009 of showing number of observations in stable, neutral, and unstable classes is an alternate approach that may better illustrate the relative occurrence of different stability classes. .

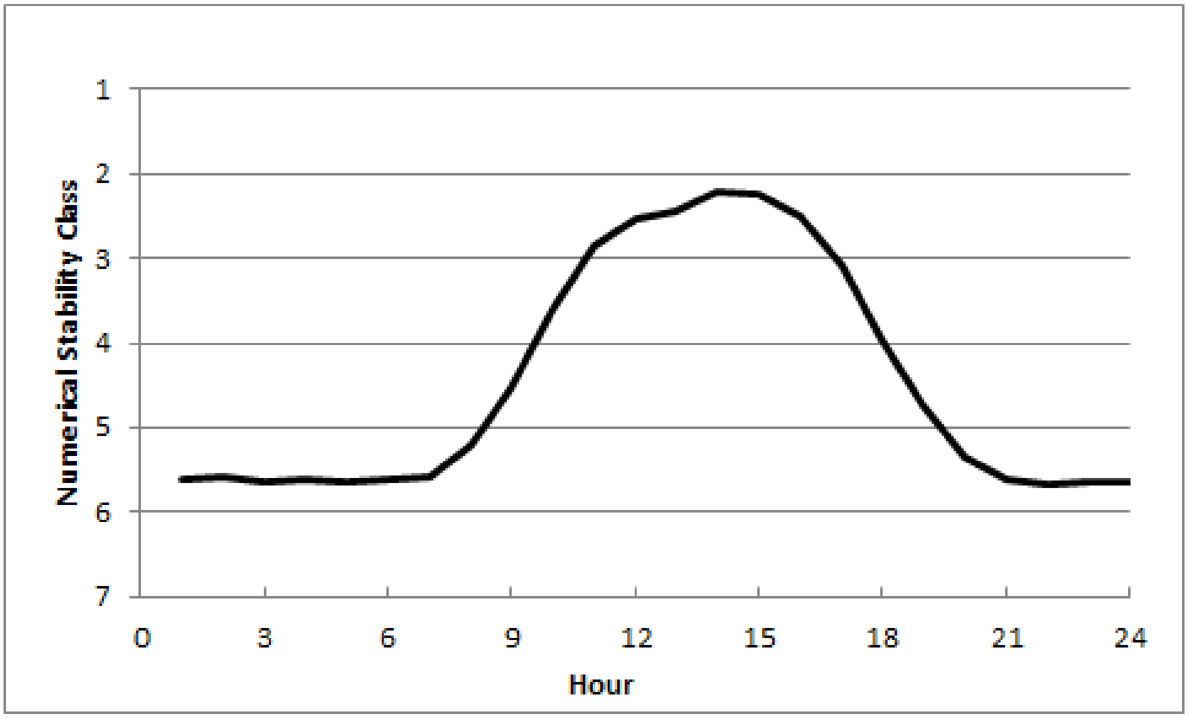

Figure 3.2-4: Average stability class by hour of day based on 1998 dataset

Table 3.2-6 and Figure 3.2-5 shows the distribution of stability classes. Stability class 4 (neutral) and 5 (slightly stable) are the most likely stability categories, consistent with the longer term trends. However, unlike the 1998-2002 5-year average, the 1998 data showed a relatively higher percentage of very unstable weather conditions. As discussed in Section 2.2.3, 5 years (1998 to 2002) of temperature difference measurements made between the 60 and 10 m (197 and 33 ft) onsite meteorological tower levels indicate that unstable categories A, B, and C occur about 6 percent, 5 percent, and 7 percent of the time, respectively. Stable categories E, F, and G occur about 29 percent, 14 percent, and 11 percent of the time, respectively. Neutral conditions (category D) occur about 28 percent of the time. However, in the 1998 dataset, stability category A (rather than stability category C) was the most likely unstable category. The stable categories, which would lead to less dispersive conditions, were consistent with the 5-year average.

Table 3.2-6: Relative occurrence of stability classes based on 1998 data

Stability Category	MACCS ISTAB	Value from met file based on 1998 data	Overall 1998-2002 value reported in licensee documentation
A	1	11%	6%
B	2	6%	5%
C	3	3%	7%
D	4	24%	28%
E	5	29%	29%
F	6	15%	14%
G	7	12%	11%

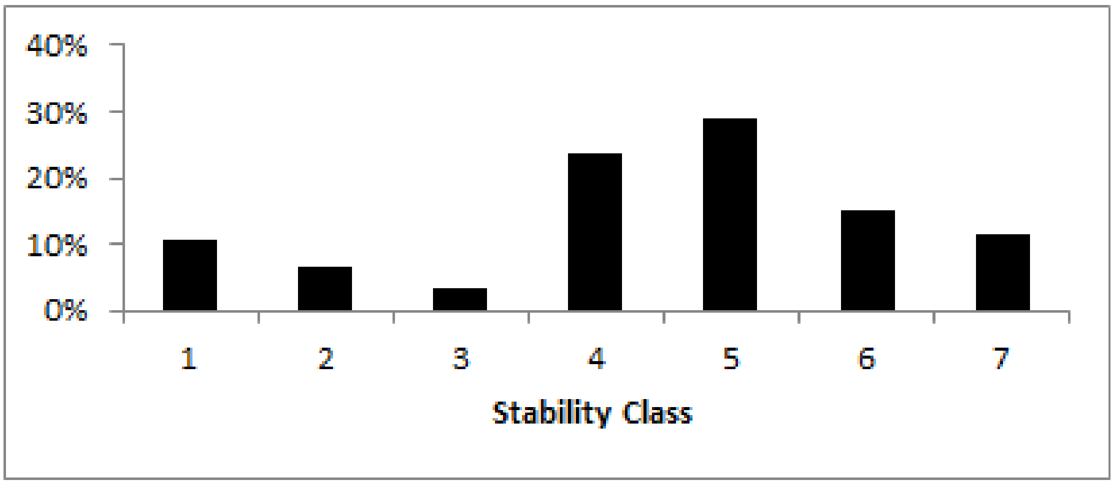

Figure 3.2-5: Occurrence of selected stability classes based on 1998 dataset

A more frequent occurrence of unstable weather may result in a relatively higher likelihood of dispersive conditions. In this regard, the 1998 dataset is less representative than the long-term average. However, as previously noted, the total rainfall in 1998 is closer to the longer term average regional rainfall, and the occurrence of stable categories is consistent. Both of these conditions are more likely to yield less dispersion, and, generally, higher consequences. Therefore, the staff does not consider this difference sufficient to eliminate the use of the 1998 data as the base case.

3.2.2.3 *Meteorological Sampling*

As previously discussed, MACCS has a number of approaches for treating weather data, ranging from direct input of weather data, sampling weather data for each day of the year, sorting weather observations into frequency-weighted bins, or simply computing results for all weather records available. Given the perceived complexity of the weather binning process and the increased computing power available over the last several decades, a direct use of all available weather data could be used to improve clarity in the discussion of the results. The project staff considered this option and determined that, when running ATMOS alone, a direct

use of all weather data would be feasible, even for simulations with many plume segments. However, when MACCS is run with multiple exposure cohorts, and particularly when the use of a threshold dose-response function is desired, the run times can still be prohibitive when multiple source terms require evaluation, as is the case in this project. Sensitivity analyses conducted for the SOARCA Peach Bottom uncertainty analysis show only a 1-2 percent difference in results using the binning approach versus all data, while reducing the computing time by a factor of 8. Therefore, the staff initially considered using the weather binning approach for the project. This option is implemented by assigning the variable METCOD the value of 2 and developing bin weighting parameters, discussed further below. However, further developments over the course of this project allowed reconsideration of this approach. In the current analysis, all available weather data was therefore used.

There are two methods for a MACCS analyst to ensure all available hourly data is used. The first is by setting METCOD to a value of 5 (which will sample a fixed number of samples from each day of the weather file) and setting the value of NSMPLS to 24, which effectively samples the entire year. The second approach is to retain the nonuniform bin sampling approach by setting METCOD to a value of 2, and then assigning each weather bin a number of samples equal to the number of observations that fell into that bin over the course of the selected year. Initially, this approach caused an out of memory error because of the large number of plume segments and cohorts used in this analysis. However, further MACCS code development for version 3.11 solved the memory problem, allowing all hours of weather data to be run. As expected, this results in proportionately longer simulation times (over a week in some cases, even for the linear non-threshold dose-response model), but changes in project schedule and other improvements allowing greater efficiency in model development and output processing allowed consideration of longer execution times. Therefore, the current approach is to run all available weather data.

Nonetheless, the weather binning approach is still described, as it can be used to explore the effect of meteorological conditions on consequences using the MACCS variable RISCAT, and would be the preferred approach if a large number of modeling cases were to be run, for example, when carrying out uncertainty or sensitivity analyses. Weather binning is a form of importance sampling that is used in MACCS and is described in Appendix B of (Jow et al. 1990). Because the key meteorological variables that affect consequences are the location and intensity of precipitation, as well as the wind speed and stability class, the weather binning algorithms in MACCS are set up to categorize similar sets of weather data based on wind speed, stability class, and the occurrence and location of precipitation. Rain bins can be defined by the user on the basis of distance and rain intensity, whereas the definition of the wind speed and stability bins are fixed within the code and cannot be changed by the user.

The process is as follows. Each of the 8760 starting times are sorted into a bin depending on whether precipitation occurs within the sequence within a specified distance of the release, and how heavy the precipitation is. The occurrence and intensity of the rain is specified in the met file, and the rain distance is calculated in ATMOS independent of the weather binning. A rain bin is defined if the rain commences before the plume has traveled more than a specified distance, defined by x=u*t. If a precipitation event does not begin within the specified distance, the

sequence is binned according to the stability class and wind speed at the beginning of the weather sequence. For example, with three rain intensity intervals (NRINTN=2) and six rain distance intervals (NRNINT=6), each sequence is assigned to one of the following bins shown in Table 3.2-7.

Table 3.2-7: Definition of meteorological bins

<table>
<tr><th colspan="7">Rain Bins</th></tr>
<tr><th rowspan="2">Rain Distance</th><th colspan="6">Rain Intensity (mm/hr)</th></tr>
<tr><th colspan="2">0-2.5 mm/hr</th><th colspan="2">2.5-7.6 mm/hr</th><th colspan="2">>7.6 mm/hr</th></tr>
<tr><td><2 miles</td><td colspan="2">Bin 17</td><td colspan="2">Bin 18</td><td colspan="2">Bin 19</td></tr>
<tr><td>2-5 miles</td><td colspan="2">Bin 20</td><td colspan="2">Bin 21</td><td colspan="2">Bin 22</td></tr>
<tr><td>5-10 miles</td><td colspan="2">Bin 23</td><td colspan="2">Bin 24</td><td colspan="2">Bin 25</td></tr>
<tr><td>10-20 miles</td><td colspan="2">Bin 26</td><td colspan="2">Bin 27</td><td colspan="2">Bin 28</td></tr>
<tr><td>20-30 miles</td><td colspan="2">Bin 29</td><td colspan="2">Bin 30</td><td colspan="2">Bin 31</td></tr>
<tr><td>30–50 miles</td><td colspan="2">Bin 32</td><td colspan="2">Bin 33</td><td colspan="2">Bin 34</td></tr>
<tr><td>>50 miles</td><td colspan="6">Not a rain bin – proceed to wind speed and stability binning</td></tr>
<tr><th colspan="7">Wind Speed and Stability Bins</th></tr>
<tr><th rowspan="2">Stability Class</th><th colspan="6">Wind Speed u</th></tr>
<tr><th>0-1 m/s</th><th>1-2 m/s</th><th>2-3 m/s</th><th>3-5 m/s</th><th>5-7 m/s</th><th>>7 m/s</th></tr>
<tr><td>A/B</td><td colspan="3">Bin 1</td><td colspan="3">Bin 2</td></tr>
<tr><td>C/D</td><td>Bin 3</td><td>Bin 4</td><td>Bin 5</td><td>Bin 6</td><td>Bin 7</td><td>Bin 8</td></tr>
<tr><td>E</td><td>Bin 9</td><td>Bin 10</td><td>Bin 11</td><td colspan="3">Bin 12</td></tr>
<tr><td>F/G</td><td>Bin 13</td><td>Bin 14</td><td>Bin 15</td><td colspan="3">Bin 16</td></tr>
</table>

By inspection of Table 3.2-7, it can be seen that the number of weather bins to be used for nonuniform bin sampling is equal to

$$NSBINS = 16 + NRNINT*(NRINTN+1).$$

Since the 16 wind speed and stability bins are fixed by the code, they are assigned bin numbers 1-16. The rain bins, which can be defined by the user and which may therefore vary in number, are assigned bin numbers by successively taking higher rain intensities and rain distances.

The number of observed weather sequences falling within each bin is used to establish the overall probability of the bin. For example, for a bin with 1100 sequences drawn from 8760 hourly observations, the bin probability is

$$1100/8760 = 12.6\%$$

Each of these bins is then sampled, with the number of samples for each bin defined by the user according to the MACCS variable INWGHT. For each sequence, the sequence probability (PRBMET) is defined by the bin frequency divided by the number of samples in the bin. For example, if 110 samples were drawn from a bin containing 1100 sequences drawn from the 8760 possible, the sequence probability would be equal to

$$PRBMET = \frac{\left(1100/_{8760}\right)}{110} = 0.11\%$$

If, on the other hand, a weather bin contains only 3 sequences out of 8760, then the bin frequency would be 0.034 percent, and if all three sequences were drawn from this bin, each would have a sequence probability (PRBMET) of 0.011 percent. The sequence weighting probability PRBMET is used to weight the result of computations using that sequence such that the results may be combined to estimate the probability distribution over all the results. For example, the mean value may be calculated simply by summing the results weighted by their respective PRBMET values.

The American Meteorological Society definition of rainfall intensity (AMS 2012) was used to define the rain intensity bins shown in Table 3.2-8.

Table 3.2-8: Rain intensity bin intervals

AMS Classification	Rain Intensity Intervals (NRINTN=2)
Light Rain	0–2.5 mm/hr
Moderate Rain	2.5–7.6 mm/hr
Heavy Rain	>7.6 mm/hr

The rain distance intervals were set with consideration of the variation in population density with distance from the site and the size of the potential evacuation. Concentrations are generally highest within a few miles of the site, and therefore a bin was defined at 2 miles. Additional intervals were defined at 5, 10, and 20 miles to capture the range in the potential evacuation radii, and an interval was defined at 30–50 miles to ensure that the effect of rain beginning within the 50-mile region containing the higher population densities associated with more densely populated areas was sampled. This results in the set of distance intervals shown in Table 3.2-9.

Table 3.2-9: Rain distance bin intervals

Rain Distance Intervals (NRNINT=6)
<2 miles
2–5 miles
5–10 miles
10–20 miles
20–30 miles
30–50 miles

This results in 34 weather bins (the 16 predefined wind speed and stability bins, and 18 rain bins).

In the L3PRA analyses, all of the hourly meteorological observations were used. However, the recommended subset based on SOARCA binning practices was developed and is also provided. This set of bin weights is suitable for use in more computationally intensive analyses, such as uncertainty or sensitivity analyses. The weather bin sampling approach allows unbiased estimates to be produced for data sets containing low frequency, high consequence results with significantly fewer computer runs needed than directly sampling all the observations. The advantage of this sampling scheme is that results which may significantly affect the mean value (e.g., events where heavy to moderate rainfall begins over a populated area) are properly weighted. If the samples were evenly distributed, a simulation which included that sequence would result in an artificially high estimate of the mean if it happened to be sampled (and, therefore, implicitly assigned a higher probability than justified) and an artificially low estimate of the mean if it were not sampled (because the results would not include the low likelihood but high consequence sequences). The number of trials selected from each bin was the maximum of 12 trials and 10 percent of the number of trials in the bin. Some bins contain fewer than 12 trials. In those cases, all of the trials within the bin are used for sampling. This strategy results in roughly 1,000 weather trials using these weather sampling inputs. These values were produced by processing the meteorological file using ATMOS with the assigned rain distance and intensity bins, and using the resulting bin classification to assign the number of samples for each bin. The number of sequences in each bin, and the resulting number of samples in each bin, are shown in Table 3.2-10 based on the 1998 lower measurement level data.

Table 3.2-10: Weather binning parameters for L3PRA project based on 1998 dataset

Bin	Bin Description	Num. in Bin	Pct.	INWGHT (SUBSET)	INWGHT (ALL)
1	Unstable (A/B), u = 0–3 m/s	631	7.2%	63	631
2	Unstable (A/B), u = >3 m/s	763	8.7%	76	763
3	Slightly unstable/neutral (C/D), u = 0-1 m/s	54	0.6%	12	54
4	Slightly unstable/neutral (C/D), u = 1-2 m/s	476	5.4%	48	476
5	Slightly unstable/neutral (C/D), u = 2-3 m/s	681	7.8%	68	681
6	Slightly unstable/neutral (C/D), u = 3-5 m/s	619	7.1%	62	619
7	Slightly unstable/neutral (C/D), u = 5-7 m/s	92	1.1%	12	92
8	Slightly unstable/neutral (C/D), u = > 7 m/s	3	0.034%	3	3
9	Slightly stable (E), u = 0–1 m/s	152	1.7%	15	152
10	Slightly stable (E), u = 1–2 m/s	819	9.3%	82	819
11	Slightly stable (E), u = 2–3 m/s	626	7.1%	63	626
12	Slightly stable (E), u => 3 m/s	362	4.1%	36	362
13	Stable (F), u = 0–1 m/s	581	6.6%	58	581
14	Stable (F), u = 1–2 m/s	1298	15%	130	1298
15	Stable (F), u = 2–3 m/s	324	3.7%	32	324
16	Stable (F), u => 3 m/s	29	0.33%	12	29
17	Light rain within 2 miles	240	2.7%	24	240
18	Light rain within 2–5 miles	50	0.57%	12	50

Table 3.2-10: Weather binning parameters for L3PRA project based on 1998 dataset (continued)

Bin	Bin Description	Num. in Bin	Pct.	INWGHT (SUBSET)	INWGHT (ALL)
19	Light rain within 5–10 miles	108	1.2%	12	108
20	Light rain within 10–20 miles	153	1.7%	15	153
21	Light rain within 20–30 miles	137	1.6%	14	137
22	Light rain within 30–50 miles	224	2.6%	22	224
23	Moderate rain within 2 miles	66	0.75%	12	66
24	Moderate rain within 2–5 miles	8	0.091%	8	8
25	Moderate rain within 5–10 miles	17	0.19%	12	17
26	Moderate rain within 10–20 miles	38	0.43%	12	38
27	Moderate rain within 20–30 miles	32	0.37%	12	32
28	Moderate rain within 30–50 miles	59	0.67%	12	59
29	Heavy rain within 2 miles	35	0.40%	12	35
30	Heavy rain within 2–5 miles	7	0.080%	7	7
31	Heavy rain within 5–10 miles	8	0.091%	8	8
32	Heavy rain within 10–20 miles	20	0.23%	12	20
33	Heavy rain within 20–30 miles	17	0.19%	12	17
34	Heavy rain within 30–50 miles	31	0.35%	12	31
TOTAL		8760	100%	1002	8760

Note: Num.: Number; Pct.: Percent

3.2.2.4 *Boundary Weather*

MACCS has the capability to apply a user-specified set of weather conditions at a predefined spatial interval, a capability known as boundary weather. NUREG-1150 (NRC 1990) and earlier studies chose to specify the occurrence of rain in the outermost spatial intervals in order to prevent radioactive material from escaping consideration. As described in Section 9.3.2.3 of NUREG/CR-2300 (NRC 1983), the rationale for this choice was the observation that the total population dose would not converge with increasing distance from the release point (i.e., the mathematical model for the population dose continued to increase as the distance from the plant increased), and it was considered preferable to use the plume-washout method as an approach to account for the impact from all of the released material rather than truncating the total population dose on the basis of dose or distance. The physical basis for this assumption is documented in Section 7 of Appendix VI of WASH-1400 (NRC 1975), which notes that tropospheric aerosols typically have a finite residence time on the order of 2-4 days (48-96 hours) before being deposited by wet deposition. Based on the data from six representative sites, WASH-1400 estimated that 100 hours was approximately the median travel time for a plume to travel a distance of 500 miles, and therefore considered the simplification of depositing any remaining airborne particulate radioactive material at 500 miles to be a reasonable approach for accounting for the eventual fate of airborne material. Similarly, NUREG-1150 chose to specify the occurrence of rain in the outermost spatial intervals beyond 500 miles. Appendix A.5.3 of NUREG-1150 characterizes this approach as “a special artifice of calculation … used to gradually deplete the plume of its remaining radionuclide content in particulate form and deposit it on the ground. The purpose of doing this was to provide a nearly complete

accounting of the radionuclides released in particulate form from the plant." Although the rationale appears to have a physical basis (i.e., finite residence time of tropospheric aerosols) and does not appear to originally have been based on the desire to perform a bounding analysis, the current version of the analysis does not report results for distances greater than 100 miles. At distances this close, use of boundary weather would not be justified, as it would result in artificially depleting the plume at an inappropriately short travel time. Since the final spatial interval in the computational grid is greater than 100 miles, the elimination of boundary weather was considered to be a reasonable approach. The last spatial interval for measured weather (LIMSPA) is therefore set to be equal to the last interval in the spatial grid.

Earlier versions of MACCS read only 120 hours of weather data from the weather file. Because of the flexibility that ATMOS allows in the definition of the spatial grid, it was possible that the 120-hour sequence of weather data used in MACCS would not be enough to carry all the plume segments out to the last spatial interval. Therefore, the defined boundary weather was used for these cases. However, MACCS now carries 1000 hours of weather data instead of 120 hours when using a weather file. The only place boundary weather is currently used is therefore outside the grid element denoted by LIMSPA. However, the user is still required to specify a set of boundary weather conditions. In addition, the specification of boundary weather conditions allows a sensitivity analysis to be conducted on the effect of boundary weather by assigning a non-zero rainfall rate and by varying the parameter LIMSPA, to determine whether boundary weather adequately captures the effect of more distant deposition. Boundary weather conditions for the mixing height, stability class, wind speed, and rainfall rate were derived based on either the mean (for wind speed and mixing height) or most likely (stability class and rainfall rate) values determined from examination of the 5-year data set. Stability class E (slightly stable) is slightly more prevalent at 29 percent of the hourly observations than stability class D (neutral, 24 percent of observations) and is selected as the boundary weather stability class. Since rainfall is relatively infrequent (in 1998, measurable rain at the site occurred on 98 out of 365 days, or 27 percent), the constant weather condition was set to a no-rainfall condition. The resulting boundary weather conditions are set as shown in Table 3.2-11.

Table 3.2-11: Boundary weather characteristics

Wind Speed (m/s)	Stability Class	Rainfall Rate (mm/hr)	Mixing Height (m)
2.3	E (5)	0	890 m

3.2.3 MACCS Meteorological Input Parameter Summary

A summary of the MACCS input parameters related to meteorological data is provided in Table 3.2-12.

Table 3.2-12: Summary of MACCS input parameters related to meteorological data

Variable	Description	Value	Source
MET file	Site Meteorological File	[*SITE*]1998LHt R2.inp	Section 3.2.2.2
MAXHGT	Flag for Mixing Height	DAY_AND_NIGHT	
LATITU	Latitude of Power Plant	[_]	
LONGIT	Longitude of Power Plant	[_]	
IRSEED	Seed for Random Number Generator	79	Section 3.2.2.3
METCOD	Meteorological Sampling Option Code	2	
NSMPLS	Number of Meteorological Samples per Bin or Day	0	
NRINTN	Number of Rain Intensity Breakpoints	2	
NRNINT	Number of Rain Distance Intervals	6	
NSBINS	Number of Weather Bins to Sample	34	
RNDSTS	Endpoints of Rain Distance Intervals (mi)	2,5,10,20,30,50	
RNRATE	Rain Intensity Breakpoints for Weather Binning (mm/hr)	2.5, 7.6	
INWGHT*	Number of Samples for Each Bin used for Nonuniform Bin Sampling	Table 3.2-10 (Column marked “ALL”)	
LIMSPA	Last Interval for Measured Weather	35	
BNDMXH	Boundary Weather Mixing Layer Height (m)	890	Section 3.2.2.4
BNDWND	Boundary Wind Speed (m/sec)	2.3	
IBDSTB	Boundary Weather Stability Class Index	5	
BNDRAN	Boundary Weather Rain Rate (mm/hr)	0	

**If a sampled subset of weather data is desired, the recommended values are provided in Table 3.2-10.*

3.2.4 Identification and Discussion of Uncertainties Related to Meteorological Data

There are a number of sources of uncertainty in the calculation. These are listed in Table 3.2-13 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.2-14 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.2-13. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS. In some cases, there may be no straightforward method to examine the impact of the uncertainty, and therefore no candidate sensitivity analysis is identified. For most of the identified sources of uncertainty related to meteorological data, the recommended approach would be benchmarking against alternate conceptual models rather than developing a sensitivity analysis using the MACCS code. Additional discussion of potential uncertainties, and approaches to evaluate them, are provided below.

Use of only a single years’ worth of data in the analysis is a source of uncertainty. Based on preliminary analyses, it was determined that the relative occurrence of stable, low wind speed conditions may be a more significant meteorological condition than total rainfall for consideration in selection of a representative weather year. However, for most of the figures of merit examined in the analysis, the mean values did not appear to be particularly sensitive to different weather conditions, as discussed in Section 4. The use of the 1998 dataset is therefore still

considered reasonable, but further work could be carried out to develop weather files for the remaining years to evaluate sensitivity of results to different meteorological datasets. Sensitivity analyses could be conducted using meteorological files based on the other years in the dataset. The licensee evaluated each of the 5 years of data from the site using MACCS and found that the 1999 dataset gave the highest dose and cost risk, with 2000 and 2001 providing 97 percent and 92 percent, respectively, of the baseline cost and dose risk.

It should be noted that the current modeling approach uses the MACCS variable RISCAT (as discussed in Section 3.7) to allow inference of how sensitive the mean value of different types of consequences could be to different weather conditions, which may vary in relative frequency of occurrence from year to year. The insights from this could be used to search for particularly significant weather conditions in alternate years or other approaches to developing a meteorological dataset that may give rise to differences in meteorological conditions such as stability, wind speed, or precipitation conditions. For most consequence measures, the mean value does not appear to be highly sensitive to different weather conditions. In such cases, the low relative frequency of adverse weather conditions is expected to offset any increased consequence associated with adverse weather conditions, at least in relation to mean consequences over all weather conditions.

Table 3.2-13: Uncertainties related to meteorological data

3.2.2.1 Selection of Data	Use of observations from a single observation point will not capture spatial variability in the winds, turbulence, or precipitation (in both the lateral and vertical direction). This could be a significant source of uncertainty, depending upon the consequence measure, the distance from the site, the characteristics of the release, and the complexity of the windfield. The effect of this uncertainty could be evaluated using analyses of benchmark analyses against alternate codes that do capture such effects, such as was conducted in (Molenkamp et al. 2004). The effect of the higher fidelity models resulted in a difference in averaged air concentration and ground deposition levels within a factor of approximately 2 out to distances of about 100 miles.
	Use of only one year of weather data introduces uncertainty due to inter-annual variability in weather. The effect of this is not expected to be a major source of uncertainty, as there is significant variability within a single year, and the effect of extreme weather (which is more likely to be observed with a longer period of record) on atmospheric dispersion generally tends to increase dispersion. The effect of this could be examined using sensitivity analyses with data sets derived from alternate years (provided that the hourly observations are available; use of daily values would be unable to capture diurnal variability). The effect could also be captured with sensitivity analyses using datasets from alternate locations, but the applicability of observations from more remote locations may not capture site-specific meteorological characteristics.
3.2.2.2 MACCS Meteorology Implementation	Use of observations from 10 m level to represent transport at all heights within the atmospheric boundary layer is a source of uncertainty, given that wind speed and wind direction change with height and that a vertical turbulence structure can develop at night with different stability conditions at different elevations. This could be a significant source of uncertainty. This could be partially examined by using a data set from higher (60 m) elevation point, or more preferably, using a model (such as HYSPLIT [Stein et al. 2015]) that explicitly models the vertical structure of transport properties.
	Very low wind speeds, and the uncertainty in turbulent dispersion at low wind speeds, cannot be accurately measured and are approximated in MACCS by assuming that any wind speed less than 0.5 m/s is modeled as 0.5 m/s. This is not expected to be a significant source of uncertainty because calm conditions are relatively infrequent, and calm winds would increase the time available for evacuation of close-in populations before significant exposures would occur.

Table 3.2-13: Uncertainties related to meteorological data (continued)

3.2.2.2 MACCS Meteorology Implementation	The use of stability classes rather than more continuous representations of turbulent dispersion is a source of uncertainty, as is the method (i.e., lapse rate versus sigma-theta or other approaches to stability classification). This could be a significant source of uncertainty, particularly if alternate methods resulted in a significantly different picture of atmospheric stability than that used in the analysis. The effect of this uncertainty could be evaluated using benchmark analyses against alternate codes that do capture such effects, such as was conducted in (Molenkamp et al. 2004). The effect of the higher fidelity models resulted in a difference in averaged air concentration and ground deposition levels within a factor of approximately 2 out to distances of about 100 miles.
	The averaging interval used to represent weather could mask variability at smaller temporal scales. The effect of this could be captured using sensitivity analyses based on 15 min averaging intervals for meteorological intervals, if such data were available. This is not expected to be a major source of uncertainty, as it is judged that hourly intervals are adequate to capture variability in the weather, particularly for prolonged releases.
	Missing meteorological data must be inferred by expert judgment, which is subject to uncertainty. It is not expected that this is a major source of uncertainty in estimates of mean consequences, as the data recovery for the selected year is quite high and the potential for the substitution process to introduce systematic or significant errors is expected to be low.
	Although the depth of the atmospheric boundary layer would vary on a daily and hourly basis, it is represented as seasonal morning (minimum) and evening (maximum) values that are not correlated with the hourly data. Likewise, the diurnal variation of the turbulence structure in the boundary layer is represented by a simplified approach with only a single mixing layer (i.e., the effect of a nighttime residual layer aloft above a stable ground-level layer is not explicitly modeled.). This could represent a significant source of uncertainty. The effect of this uncertainty could be evaluated using analyses of benchmark analyses against alternate codes that do capture such effects, such as was conducted in (Molenkamp et al. 2004). The effect of the higher fidelity models resulted in a difference in averaged air concentration and ground deposition levels within a factor of approximately 2 out to distances of about 100 miles.

Table 3.2-13: Uncertainties related to meteorological data (continued)

3.2.2.3 Weather Bin Sampling	Use of only a subset of weather trials can introduce uncertainty in the estimates of the annual statistics. The effect of this has been evaluated in previous studies and generally found to be small (e.g., 1-2 percent in the SOARCA Peach Bottom uncertainty analysis), but the effect of sampling for this particular analysis could be quantified using sensitivity analyses (i.e., using all available weather data, using multiple runs to generate different sets of weather sequences, etc.). The effect would be expected to be most significant for relatively high consequence low conditional likelihood effects, such as early health effects, which are unlikely to be observed under most weather conditions. The current base-case model includes all available hours.
3.2.2.4 Boundary Weather	Use of boundary weather that differs from actual weather is unrealistic. Although boundary weather is not used in this analysis, the uncertainty introduced by the boundary weather approach could be examined using sensitivity analysis varying LIMSPA to examine whether boundary rainout adequately envelopes impacts beyond the measured weather interval.

Table 3.2-14: Potential sensitivity analyses to address uncertainties related to meteorological data

Analysis	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
ME_1	Determine influence of selected weather year by running different years of meteorological data	Weather file	Minor changes in most results. Potentially noticeable change for low frequency results characterized by high-dose thresholds (i.e., early injuries or fatalities)	Alternate input decks
ME_2	Determine influence of sampling only a subset of weather trials	INWGHT and/or METCOD/NSMPLS	Minor changes in most results; potentially larger changes in early health effect measures	Cyclic file set (if varying INWGHT)

3.3 Atmospheric Dispersion and Deposition (AD)

3.3.1 Assumptions and Known Limitations

- The MACCS straight-line Gaussian plume segment model with provisions for meander and surface roughness is assumed to adequately represent atmospheric dispersion and deposition across the range of prospective weather conditions.
- After a plume segment is released, the plume segment is assumed to not change direction (i.e., straight-line), and therefore does not account for variations in wind direction, wind field, or topography. This is expected to provide results that are reasonable in an average, ensemble sense (in the sense that changes in wind direction during transport are assumed to be offsetting), but the results from any given weather trial may not be representative of that specific meteorological sequence.
- Site-specific physical plant characteristics (e.g., building dimensions and stack heights) are used to determine height of releases and building wake.
- Buoyant plume rise is modeled using a buoyancy flux estimated from the gas flow rate and density of the released gases.
- Building wake effects are estimated using a virtual source. The initial plume size is assumed to be characteristic of the building from which the plume is released.
- Multi-phased releases that use hourly plume segments are assumed to be adequate to account for temporal variations in meteorological conditions (such as wind direction).
- Dry deposition velocities are calculated depending on the aerosol sizes used by MELCOR. Geographic or temporal variations in deposition velocity (e.g., due to changes in wind speed or surface roughness) are not included.
- Wet deposition velocities were based on SOARCA values and are the same for all source terms and weather conditions.
- The exclusion area, which is an irregular polygon, was modeled as a circular area with a radius of 0.75 miles.
- Wet deposition is based on parameter estimates appropriate for liquid precipitation (rain) rather than frozen precipitation (snow/ice) or fog.
- Based on benchmarking exercises documented in NUREG/CR-6853 (Molenkamp et al. 2004), the use of the straight-line Gaussian plume model is assumed to reasonably represent atmospheric and ground deposition variations with distance to a range of 100 miles.
- The mixing layer serves as an impenetrable boundary and can be modeled by assuming complete reflection of the plume from the mixing layer height.
- There are no changes in aerosol properties (e.g., deposition velocity) after release.

3.3.2 Technical Discussion

Because they are simple and computationally efficient, Gaussian plume models have often been used to model atmospheric dispersion in reactor accident risk assessments (see, for example, [NRC 1983]). Gaussian plume models assume that the diffusion of gas molecules and aerosol particles in the plume during its downwind transport can be modeled as a random walk that generates a normal distribution for air concentration in all directions. Vertical and horizontal plume distributions differ significantly and must be separately calculated. During downwind transport, atmospheric turbulence causes plume segments to expand in all directions with the rate of expansion increasing as atmospheric turbulence increases. Vertical expansion of the plume is increased by surface roughness and constrained by the ground and by the location of inversion layers that limit vertical motion of air parcels. Crosswind spreading of the plume segment along the y-direction is unconstrained. The effective crosswind dimensions of a plume segment are increased by lateral meander of the plume about its centerline trajectory.

MACCS models plume dispersion during downwind transport using a Gaussian plume segment model, which allows for variation in the source term and changes in wind direction, wind speed, and atmospheric stability, but does not allow a change in the plume segment direction once the segment has been released. Testing of this simplifying dispersion and deposition assumption was performed in NUREG/CR-6853 (Molenkamp et al. 2004) using comparison of MACCS2 to ADAPT/LODI (Atmospheric Data Assimilation and Parameterization Techniques/ Lagrangian Operational Dispersion Integrator), a state-of-the-art, three-dimensional advection dispersion code (Sugiyama and Chan 1998; Nasstrom et al. 2000) . Two comparison metrics were used. The first metric consisted of the average exposure and deposition in four circular rings around the source at distances between 14.4 and 16.1, 30.6 and 32.2, 78.7 and 80.5, and 159.3 and 160.9 km (9 and 10, 19 and 20, 49 and 50, and 99 and 100 miles). The second metric considered the average exposure and deposition in arc-sectors using the same four distances for the arcs and the 16 compass sectors from N clockwise around to NNW, a total of 64 values for each exposure (depositing and non-depositing material) and deposition (for depositing material). For the parameters used in the analysis, the MACCS ring average values ranged from a minimum of 0.64 to a maximum of 1.58 times the corresponding LODI ring average, with higher ratios occurring for the 16.1-km (10-mile) ring and lower for the 80.5- and 160.9-km (50- and 100-mile) rings. All these ratios are well within a factor of 2. The arc-sector exposures and depositions for MACCS were also usually within a factor of 2 of the corresponding value for LODI. Of the 192 exposures and depositions (4 arcs, 16 sectors, 2 exposures and 1 deposition), only 9 were more than twice as large (all in the 16.1-km arc) and 12 were less than half as large (4 in the 80.5-km and 8 in the 160.9-km arc), and these were usually in sectors where the exposure or deposition was smaller. Differences greater than a factor of 3 occurred only twice. Overall, the arc average and the great majority of the arc-sector average exposures and depositions were within a factor of 2 when comparing MACCS to LODI. In contrast to the L3PRA project, (Molenkamp et al. 2004) only used a single deposition velocity for MACCS; however, it does provide a basis for use of the plume segment model as a reasonable approach for estimating average concentrations and depositions out to 100 miles.

The horizontal and vertical extent of plume segments is expressed in terms of the horizontal (σ_y) and vertical (σ_z) standard deviations of the normal concentration distributions that characterize a Gaussian plume. The Gaussian equations implemented in MACCS are derived assuming that turbulent velocities are negligible compared to the mean wind speed (Koa 1984). Accordingly, MACCS assumes that the initial length of plume segments is unaffected by dispersion during downwind transport (i.e., plume segment lengths are constant once release from containment is completed). When not constrained by the ground or by inversion layers, the Gaussian plume equation has the following form (Turner 1970):

$$\chi(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \mathrm{e}^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \ \mathrm{e}^{-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2}$$

where $\chi(x,y,z)$ is the time-integrated air concentration (Bq·s/m^3) at the downwind location (x, y, z), Q is the released activity (Bq), u is the wind speed (m/s), σ_y and σ_z are the horizontal (σ_y) and vertical (σ_z) standard deviations of the normal concentration distributions that characterize a Gaussian plume, and h is the stabilized height (effective release height) of the plume segment centerline (m).

Once a plume segment has expanded sufficiently in the vertical dimension so that further vertical expansion is constrained by the ground and/or the capping inversion layer, this equation is no longer applicable. To treat restricted growth in the vertical dimension, the ground and the inversion layer are treated as impenetrable, reflecting boundaries. Mathematically, reflection is accomplished by the addition of mirror image sources above the inversion layer and below the plane of the ground. At each spatial interval along the plume segment's trajectory, MACCS tests for the occurrence of a uniform concentration distribution in the vertical direction (well-mixed plume segment between the ground and the capping inversion layer). Once a uniform vertical distribution is attained, the mathematical form reduces to the following equation:

$$\chi(x,y,z) = \frac{Q}{\sqrt{2\pi} u \sigma_y H} \mathrm{e}^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2}$$

where H is the height (m) of the capping inversion layer, that is, the height of the mixing layer. MACCS switches to this formulation when σ_z > 33.3 H . This criterion approximately corresponds to the requirement that the results of calculations with mirror sources agree with the simplified calculation to within 1 percent.

The downwind transport of a plume segment is affected by turbulence from building wake effects, buoyant plume rise, and temporal changes in meteorological conditions during the downwind transport of the plume segment. The basic Gaussian plume segment model described above is therefore adapted by using adjustments to account for these phenomena. The buoyancy driven rise of a plume segment above the point of release is based on differences in the composition and temperature of a plume relative to the ambient atmosphere, and can be estimated based on empirical models. Turbulence induced by building wake effects can create a strong degree of spreading in both the vertical and horizontal dimensions near the

source, and can also trap a buoyant plume, preventing it from rising to the level predicted by the plume rise equations. Adjustments for building wake effects, plume meander, and for changes in stability class (and thus the rate of plume segment growth) are accounted for in MACCS by using a virtual source (described in Section 2.9 of [Jow et al. 1990]) to yield the appropriate plume dimensions. The initial plume size (σ_{y}, σ_{z}) is specified based on wake effects from the reactor building complex, and an effective virtual source location that is behind the actual release location is computed based on the meteorological conditions prevailing at the time of the release (described in more detail in Section 3.3.2.2). When the plume segment reaches a distance beyond which short-term plume meander is significant, or when the stability class changes, continuity in the plume dimensions is obtained by recomputing the virtual source location.

Several of the properties that influence these processes are determined by the physical characteristics of the release point and the results of the accident progression modeling, and are therefore considered as part of the transition from the Level 2 analysis to the Level 3 analysis. These include the elevation of the release, the building height, and effective dimensions of the wake induced by the structure from which the aerosols are released. The amount of buoyant plume rise requires the determination of the buoyancy flux of the plume, based on either the heat content or the density and flow rate of the plume segment. These parameters are computed by MELCOR and are parsed by MelMACCS to define the plume segment, as discussed in Section 3.1.2.7.

The amount and type of radioactive material in the plume is also affected by the depletion of the plume by wet or dry deposition and by radioactive decay and ingrowth. Dry deposition is the process by which aerosols are removed from the atmosphere by the combined effects of gravitational settling of materials onto, impaction on, and diffusion to the ground (Sehmel 1984). Wet deposition is the process whereby the aerosols are washed or rained out from the plume and deposited on the ground surface. As described in NUREG/CR-2300 (NRC 1983), if a plume of radioactive material encounters precipitation as it travels downwind, aerosols are deposited onto the ground either (1) through rainout, an in-cloud scavenging process in which the radioactive aerosol is a source of condensation nuclei that act as centers for the formation of water droplets, or (2) by washout, a below-cloud process in which falling water droplets collide with and collect the radioactive aerosols that make up the radioactive plume. The effect of both mechanisms are treated by determining the fraction of material that is not removed by either wet or dry deposition and adjusting the effective source strength in the concentration calculation. MACCS handles the depletion of the plume by adjusting the effective source strength, Q, to account for the depletion during travel, as well as decay and ingrowth of radioactive materials.

Development of the atmospheric dispersion and deposition model in MACCS involves the following six steps (described in the subsections that follow):

- Selection of an approach for treatment of wind shifts and definition of a spatial grid on which to carry out calculations (Section 3.3.2.1)
- Development of parameters to account for increased dispersion due to building wake effects (Section 3.3.2.2)

- Development of parameters for modeling buoyant plume rise (Section 3.3.2.3)
- Estimation of regional surface roughness to be used in estimation of both enhanced vertical dispersion as well as modeling of dry deposition (Section 3.3.2.4)
- Development of vertical and crosswind diffusion parameters, including modifications to address enhanced vertical dispersion due to surface roughness and enhanced crosswind dispersion due to plume meander (Section 3.3.2.5)
- Development of parameters to model dry and wet deposition (Section 3.3.2.6)

3.3.2.1 *Wind Shift Treatment and Spatial Grid Definition*

MACCS allows several options for the treatment of shifts in the wind direction, based on the selection of the variable IPLUME. The wind rotation option serves the purpose of maximizing the information while minimizing computational work. For each weather trial, wind rotation considers the possibility that, for otherwise similar conditions, the wind could have blown in any of the compass directions. Thus, MACCS evaluates the consequences that would have resulted for each wind direction, but accounts for the relative frequency that the wind blows in each compass direction. The wind rotation model assumes that, other than population density, the problem is axisymmetric. However, this is not the case when the network evacuation model is employed, as is the case for the L3PRA project. Project staff therefore used the wind shift without rotation (IPLUME = 3) option in conjunction with a release split into approximately hourly plume segments for the risk-significant plume segments. Matching the duration of each plume segment with the available hourly observational wind data allows a more realistic treatment of the effect of fluctuations in wind direction on downwind exposures.

A spatial grid was developed to address the full range of planned analyses for the project. The modeling domain is defined within MACCS by the variable NUMRAD (the number of radial intervals), NUMCOR (the number of compass sectors), and SPAEND (the radial distance from the release point for each radial interval). The grid definition used in this project was adapted from the SOARCA project, consisting of 64 compass sectors and 35 radii. Grid spacing was defined at a finer resolution at closer distances. The outer limits extend to 1,000 miles, consistent with NUREG-1150 and SOARCA. However, results at distances greater than 100 miles are not reported, as discussed previously. Results at distances of greater than 100 miles are only used for checking convergence of selected results. Because the exclusion area boundary (EAB) is irregular, but must be defined in the site file as a single radius, a single value of 0.75 miles (corresponding to the outer limit of ring 3) was used to define the EAB. The radial distances used for the computational grid are listed in Table 3.3-1.

Table 3.3-1: Grid definition

Radial Interval number	End of Radial Interval (km)	End of Radial Interval (mi)
1*	0.4	0.25
2*	0.8	0.50
3*	1.2	0.75
4	1.6	1.00
5	2.8	1.75
6	3.2	2
7	4.8	3
8	6.4	4
9	8.0	5
10	9.7	6
11	11	7
12	12	7.5
13	13	8
14	14	9
15	16	10
16	18	11
17	19	12
18	20	13

Radial Interval number	End of Radial Interval (km)	End of Radial Interval (mi)
19	21	13
20	23	14
21	24	15
22	28	18
23	32	20
24	36	23
25	40	25
26	48	30
27	64	40
28	80	50
29	113	70
30	161	100
31	241	150
32	322	200
33	563	350
34	805	500
35	1609	1000

**Intervals are within the exclusion area as modeled in the analysis*

3.3.2.2 *Building Wake Effects*

Mixing of the plume into the wake of the building from which the release occurs generally determines the initial crosswind and vertical dimensions of the plume. The treatment of wake effects in MACCS is based on the review by (Hosker 1984), who describes (Section 7.8.2.2) several approaches to treating the concentrations downwind of the cavity region. The approach used in MACCS, as described by (Sprung et al. 1990) and (Chanin and Young 1998a), Section 5.10), employs the virtual source approach described on pages 32-34 of (Turner 1970), in which an initial plume dimension is assigned based on the characteristics of the building from which the release occurs. For the purpose of initializing plume dimensions, the plume centerline is assumed to be at ground level and in the middle of the downwind face of the building. The initial plume dimensions are assigned by assuming that the plume concentrations at the sides and roofline of the building from which the release occurs are 10 percent of plume centerline concentrations (i.e., building edges are 2.15 sigma from the plume centerline), yielding initial values of the horizontal and vertical standard deviations of the Gaussian plume given by

$$\sigma_{y,init} = \frac{W_b}{4.3} \text{ and } \sigma_{z,init} = \frac{H_b}{2.15}$$

where W_b is the width of the building from which release occurs (m) and H_b is the height of the building from which release occurs (m). Project staff used the dimensions of the structure from which the release is modeled to occur to initialize the plume dimensions, consistent with

SOARCA practice. The initial plume dimensions are therefore a characteristic of the MELCOR flowpath from which the plume segment is released. The characteristics of each MELCOR flowpath are tabulated in Table 3.3-2.

Table 3.3-2: Release path parameters for dispersion modeling

Description	MELCOR Flowpath	Release Height (m) PLHITE	Building Height (m) BUILDH	$\sigma_{y,init}$ (m) SIGYINIT	$\sigma_{z,init}$ (m) SIGZINIT
SG 1 SRV tailpipe	372	13	55	10.4	25.9
SG 1 SRV tailpipe	373	13	55	10.4	25.9
SG 1 SRV tailpipe	374	13	55	10.4	25.9
SG 1 SRV tailpipe	375	13	55	10.4	25.9
SG 1 lowest setpoint SRV tailpipe	376	13	55	10.4	25.9
SG 1 ARV tailpipe	377	13	55	10.4	25.9
SG 1 PORV leakage	379	13	55	10.4	25.9
SG 2 SRV tailpipe	472	13	55	10.4	25.9
SG 2 SRV tailpipe	473	13	55	10.4	25.9
SG 2 SRV tailpipe	474	13	55	10.4	25.9
SG 2 SRV tailpipe	475	13	55	10.4	25.9
SG 2 lowest setpoint SRV tailpipe	476	13	55	10.4	25.9
SG 2 ARV tailpipe	477	13	55	10.4	25.9
SG 2 PORV leakage	479	13	55	10.4	25.9
SG 3 SRV tailpipe	572	13	55	10.4	25.9
SG 3 SRV tailpipe	573	13	55	10.4	25.9
SG 3 SRV tailpipe	574	13	55	10.4	25.9
SG 3 SRV tailpipe	575	13	55	10.4	25.9
SG 3 lowest setpoint SRV tailpipe	576	13	55	10.4	25.9
SG 3 ARV tailpipe	577	13	55	10.4	25.9
SG 3 PORV leakage	579	13	55	10.4	25.9
SG 4 SRV tailpipe	672	13	55	10.4	25.9
SG 4 SRV tailpipe	673	13	55	10.4	25.9
SG 4 SRV tailpipe	674	13	55	10.4	25.9
SG 4 SRV tailpipe	675	13	55	10.4	25.9
SG 4 lowest setpoint SRV tailpipe	676	13	55	10.4	25.9
SR 4 ARV tailpipe	677	13	55	10.4	25.9
SG 4 PORV leakage	679	13	55	10.4	25.9
Piping penetration area filtration and exhaust system exhaust	27	13*	55	10.4	25.9
Normal Containment Leakage	820	42	55	10.4	25.9
Normal Containment Leakage	821	25	55	10.4	25.9

Table 3.3-2: Release path parameters for dispersion modeling (continued)

Description	MELCOR Flowpath	Release Height (m) PLHITE	Building Height (m) BUILDH	$\sigma_{y,init}$ (m) SIGYINIT	$\sigma_{z,init}$ (m) SIGZINIT
Normal Containment Leakage	824	25**	55	10.4	25.9
Containment Overpressure	841	0	55	10.4	25.9
Containment Overpressure	842	0	55	10.4	25.9
Normal Aux Building Leakage	997	0	14	8.7	6.6
Normal Aux Building Leakage	998	6	14	8.7	6.6
Tendon gallery access shafts (2 of 3)	844	0	14	8.7	6.6
Aux Building Overpressure	995	11	14	8.7	6.6

** Release height is in error. Correct release height should be 55 m*
*** Release height is in error. Correct release height should be 16 m.*

3.3.2.3 *Plume Rise*

There are three basic components of the plume rise models in MACCS: (1) liftoff of buoyant plumes from a building wake, (2) plume rise under stable conditions (stability classes E and F), and (3) plume rise under unstable and neutral atmospheric conditions (stability classes A to D). Each of these aspects of plume rise is described in this section. When wind speeds are high, a buoyant plume segment that is released into a building wake is unable to escape from the wake. In MACCS, escape of a buoyant plume segment from a building wake is governed by a liftoff criterion that was originally proposed by Briggs (Briggs 1973b) and validated by experiments performed at the Warren Spring Laboratory in Great Britain (Hall and Waters 1986). The criterion states that plume rise occurs only when the wind speed upon release of the segment is less than a critical wind speed (u_c) that is calculated using the following formula:

$$u_c = \left[\frac{9.09F}{H_b}\right]^{\frac{1}{3}}$$

where H_b is the height of the building from which the plume is escaping (m) and F is the buoyancy flux (m^4/s^3). The buoyancy flux F can be computed either from the sensible heat release rate or by using the density and flow rate of the plume. Under standard atmospheric conditions, the sensible heat release rate $\dot{Q}$ (in watts, determined by dividing the sensible heat content of the plume segment by its release duration) is related to the buoyancy flux, F, by the following formula:

$$F = 8.79 \cdot 10^{-6} \cdot \dot{Q}$$

To account for the release of gases that are more or less dense than air, such as hydrogen and steam, as well as releases at elevated temperatures, the plume density and mass flow rate may be used to estimate the buoyancy flux by the following formula:

$$F = \frac{g}{\pi}\left[1 - \frac{\rho}{\rho_a}\right]\frac{\dot{m}}{\rho}$$

where g is the acceleration due to gravity (9.8 m/s^2), ρ is the mass density of the plume segment (kg/m^3), ρ_a is the mass density of surrounding air at ambient conditions (1.178 kg/m^3), and $\dot{m}$ is the mass flow rate of the plume (kg/s). The L3PRA project used this density and flow model in MACCS (set by assigning a value of "DENSITY" to the MACCS variable PLMMOD) to compute the buoyancy flux in order to account for the potential effects of the release of steam and hydrogen during an accident.

If a plume is not captured within a building wake (i.e., if liftoff occurs), MACCS models continuing plume rise until it is terminated by any of the following conditions:

- Δh reaches a final rise height, as defined below
- The height of the plume centerline reaches the mixing height (height of the capping inversion layer)
- One hour has elapsed since release of the plume segment began

MACCS has two options for modeling plume rise. This analysis uses the MACCS improved plume rise model, which is described below. When atmospheric conditions are stable (stability class E or F), the following formula based on the work of Briggs (Hanna et al. 1982) is used determine the final rise height in the improved MACCS model[13]:

$$\Delta h_{final} = 2.4\left(\frac{F}{\bar{u}S}\right)^{1/3} \text{, if stability class is E or F}$$

where $\bar{u}$ is the wind speed (m/s) averaged between the initial height and the current location (x, h) and S is a stability parameter (s^{-2}) defined by

$$S = \frac{g}{T_a}\left[\frac{\delta T_a}{\delta z} + \frac{g}{c_p}\right].$$

Within MACCS, the ambient temperature T_a is taken as the International Civil Aviation Organization standard atmosphere (West 1972) value of 288.16 K (15°C) and $\frac{g}{c_p}$ is the dry adiabatic lapse rate (0.98 K/100 m). The ambient temperature lapse rate $\frac{\delta T_a}{\delta z}$ (K/m) is derived based on the stability class from the meteorological data. Regulatory Guide 1.23 specifies ranges for temperature lapse rates for the six atmospheric stability classes A through F. The values of the stability parameter S used in MACCS were derived using midpoint values for these

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[13] Note that although MACCS uses a coefficient of 2.4, there are a number of different values for the value of the leading coefficient. (Briggs, 1970) Equation 4 gives a value of 2.9. Table 4 of (Briggs, 1975) shows a range of values from 1.8 to 3.4, and recommends a value of 2.6, which is the value recommended in Equation 2.19 of (Hanna, et al., 1982). Because the final rise height is linear with respect to the leading coefficient, adopting the more common coefficient would result in a slight increase in plume rise, which could be less conservative.

lapse rate ranges. Class E has a lapse rate range midpoint of 0.5 K/100 m and Class F a midpoint of 2.75 K/100 m. Substitution of these midpoint values results in values of $5.04\text{x}10^{-4}$ s^{-2} and $1.27\text{x}10^{-3}$ s^{-2} for the stability parameter S for stability Classes E and F, respectively.

When atmospheric conditions are neutral or unstable (stability classes A through D), plume rise is treated using the Briggs "two-thirds" law for bent over plumes (Hanna et al. 1982):

$$\Delta h(x) = \frac{1.6F^{\frac{1}{3}}x^{\frac{2}{3}}}{\bar{u}}$$

where Δh is the plume rise (m) measured from the initial release height. The final rise height is determined in the improved MACCS plume rise model using the following formulae based on the work of (Briggs 1970):

$$\Delta h_{final} = \frac{38.7F^{0.6}}{\bar{u}}, \text{ if F≥55 and stability class is A through D}$$

$$\Delta h_{final} = \frac{21.4F^{0.75}}{\bar{u}}, \text{ if F<55 and stability class is A through D}$$

Because near-surface wind speeds increase with altitude, these formulations overestimate plume rise if surface wind speeds are used to calculate Δh. For purposes of calculating plume rise, wind speeds aloft are estimated from surface wind speeds (typically measured at 10 m) using the following equation (Hanna et al 1982):

$$u(z) = u_{surf}\left(\frac{z}{z_{surf}}\right)^p$$

where u_{surf} is the surface wind speed (m/s) at the reference height z_{surf}, (usually 10 m), u(z) is the wind speed (m/s) at the height z, and p is a parameter (dimensionless) that varies with stability class and surface roughness as shown below, reproduced from (Hanna et al 1982).

Stability Class	A	B	C	D	E	F
Urban Surfaces	0.15	0.15	0.2	0.25	0.4	0.6
Rural Surfaces	0.07	0.07	0.1	0.15	0.35	0.55

Source: reproduced from (Hanna et al. 1982).

The reference height z_{surf} is assumed to be 10 m in the code. The values of the exponent *p* for six stability classes for rural area surfaces shown above are hardwired into the code. The maximum value of z in MACCS is 200 m.

The individual numerical coefficients used by these models are fixed in the code with no provision for their modification by the user. While it is not possible for the user to vary the individual coefficients utilized by the plume rise model, it is possible to modify their end results by the specification of linear scaling factors, SCLCRW, SCLADP, and SCLEFP. SCLCRW is a

scaling factor for the critical wind speed and is set such that values less than unity make liftoff less likely to occur. SCLADP and SCLEFP are scaling factors for the final plume rise calculations for unstable and neutral (stability classes A-D) and stable (E-F) atmospheric conditions, respectively, In the L3PRA project, no scaling is used and these factors are set to unity. These values may be varied parametrically in sensitivity analyses to evaluate the significance of uncertainties in the treatment of plume rise.

3.3.2.4 *Surface Roughness*

Surface roughness affects both vertical dispersion and dry deposition velocities. The project team reviewed land use surrounding the site, aerial photographs of the region, and 2013 data from the USDA CropScape database on land use. Staff also reviewed references which evaluated considerations for selecting surface roughness values at the nearby industrial complex. As discussed in Section 2.2, the area within 40 km (25 mi) of the site is predominantly evergreen forest and wooded wetlands, with a mix of woodland and cropland (to the south and west) and woodland (to the north and east.) In light of the large structures (such as cooling towers and site facilities) close to the potential release points and the predominance of woodland close to the site, and the uncertainty and variability in the roughness height associated with land use in the region surrounding the site, the staff has selected 100 cm for use in dispersion and deposition scaling to account for the relatively high level of surface roughness associated with forested cover.

3.3.2.5 *Dispersion/Turbulence Parameterizations*

The Gaussian plume segment model requires two spatially dependent diffusion parameters, $\sigma_y(x)$ and $\sigma_z(x)$, to estimate the atmospheric dispersion. These parameters are typically developed by empirical expressions derived from field experiments (see [Draxler 1984] for a summary of major field experiments) based on stability class and travel distance. The model for determining these parameters is set in MACCS by assignment of the variable NUM_DIST. If the variable is not assigned or is assigned a value of zero, MACCS uses a function that assumes that the diffusion parameters follow a power-law relationship over the entire spatial range of the model as defined below:

$$\sigma_y(x) = A_y \cdot \left(\frac{x}{x_0}\right)^{B_y}$$

$$\sigma_z(x) = A_z \cdot \left(\frac{x}{x_0}\right)^{B_z}$$

where x is the downwind distance and x_0 is the downwind distance scale, typically expressed as 1 m.

Because the same power-law parameters generally do not apply over all spatial scales, this approach requires the use of a set of power-law coefficients optimized for a particular distance range. However, it facilitates the conduct of quantitative uncertainty analyses by minimizing the

number of parameters that must be correlated. If NUM_DIST is set to a value between 3 and 50, it defines the dimensions of a distance-based lookup table, which allows the implementation of a wide variety of empirical or theoretical models. The value of the diffusion parameter at a specific distance is computed by using an interpolation algorithm in conjunction with the lookup table parameters. Use of this option allows the user more flexibility in representing dispersion over a range of distances. In addition, by setting the DISPMD variable to LRTIME, MACCS has the capability to shift to a time-based dispersion model at a user-specified distance, in which the plume standard deviation is assumed to grow as a linear function of time after the specified distance. Within 30 km of the release point, the L3PRA project uses the approach followed in SOARCA of using a power-law formulation rather than a distance lookup table. However, for distances greater than 30 km, the L3PRA project follows the approach used in (SNL 2019) and switches to a time-based plume expansion model, as discussed later in this section.

Typical parameterizations used for close-in calculations (over a distance of a few kilometers) are based on the Pasquill-Gifford diffusion curves (Pasquill 1961; Gifford 1976), which were developed from the 1956 Prairie Grass diffusion experiment. A variety of parameter systems are discussed in Section 2.3.3.2 of (Till and Meyer 1983):

- the Pasquill-Gifford system
- (Klug 1964, 1969), who reevaluated the results form tracer experiments that considered data from additional studies with ground-level, short duration releases at low surface roughness sites, with applicability out to a few kilometers
- Tracer experiments evaluated by (Singer and Smith 1966) from elevated (108 m) releases of approximately 1-hour duration over medium roughness terrain, with measurement distances out to 60 km
- Tracer experiments evaluated by (McElroy and Pooler 1968) from ground-level releases of approximately 1-hour duration over a relatively flat urbanized area out to distances of up to 16 km
- Experiments at Julich Nuclear Research Center in Germany, which involved 1-hour releases from three heights (50, 100, and 180 m) which were conducted over farmland with medium surface roughness with measurements taken out to a distance of up to 11 km (Vogt 1977; BMI 1981; Geiss 1982; Kiefer et al. 1979)

Summarizing data from (Vogt 1977), Table 2.8 of (Till and Meyer 1983) provides diffusion coefficients of these different systems of diffusion parameters for all stability classes. Briggs (1973a) synthesized information from a number of experimental studies to yield parameterizations for a range of distances and land uses. An analytical formulation for the Briggs coefficients is presented in (Hanna et al. 1982).

The Tadmor and Gur parameterization (Tadmor and Gur 1969), as corrected by (Dobbins 1979) of the Pasquill-Gifford curves was the basis for the power-law parameters in the original MACCS code (see Table 2.2 of [Jow et al. 1990]). NUREG-1150 (as described in Section 2.4 of [Sprung et al. 1990]) considered analytical fits to data from Prairie Grass as reflected in the Tadmor and Gur formulation, as well as analytical fits from Klug and from the Julich experiments. (Sprung et al. 1990) recommended continued use of the Tadmor and Gur fits

because “relative to their uncertainties all of the fits are more or less equivalent and because the Tadmur (sic) and Gur fits have been used in most previous NRC consequence modeling studies.”

In the early 1990’s, a joint effort of the NRC and the Commission of European Communities (CEC) was undertaken to develop information to support uncertainty analyses of their respective probabilistic consequence codes. The results of an expert elicitation of factors related to dispersion and deposition are documented in (Harper et al. 1995). That study developed the technical basis for defining the plume horizontal and vertical standard deviation for a range of stability conditions, a mix of surface roughness, and downwind distances ranging from 500 m to 30 km. Conversion of the elicitation data into parameters suitable for a power-law formulation is documented in NUREG/CR-7161 (Bixler et al. 2013), and formed the basis for the diffusion parameterization used in SOARCA. Further work to refine uncertainty distributions for SOARCA were carried out and are documented in Section 5.9.6 of (SNL 2019). However, the median values from NUREG/CR-7161 continue to be regarded as best estimate parameters. All of these studies produce estimates of plume standard deviation applicable for values relatively close, from several kilometers out to some tens of kilometers. Consistent with (SNL 2019), a time-based expansion model for the crosswind plume standard deviation (σ_y) was adopted at distances greater than 30 km.

Because the formulation developed in (Bixler et al. 2013) represents a range of experts, a mix of surface roughness characteristics, and explicitly considers distances out to 30 km, the L3PRA project has elected to use the power-law formulation based on median parameters from (Bixler et al. 2013) as the basis for distances out to 30 km, and to use the time-based expansion model for greater distances. The values for the power-law coefficients used in the base case are provided in Table 3.3-3[14]. The use of the median value parameter estimates is consistent with the approached used in SOARCA, and the use of the time-based expansion is consistent with (SNL 2019). The use of the power-law formulation has been chosen because it will facilitate the potential for future uncertainty and sensitivity analyses.

Table 3.3-3: Diffusion parameters: median value from expert elicitation

	Sigma-y (m)		Sigma-z (m)	
P-G Stability Class	A_y	B_y	A_z	B_z
A	0.7507	0.866	0.0361	1.277
B	0.7507	0.866	0.0361	1.277
C	0.4063	0.865	0.2036	0.859
D	0.2779	0.881	0.2636	0.751
E	0.2158	0.866	0.2463	0.619
F	0.2158	0.866	0.2463	0.619

[14] Note that the same parameter values are assigned for classes A/B and for classes E/F. Use of the NUREG/CR-7161 correlations would appear to result in effectively four stability classes: unstable (A/B), slightly unstable (C), neutral (D), and stable (E/F/G).

Source: (Bixler et al. 2013)

One effect of surface roughness is to increase the vertical dispersion, and its effect is implemented in MACCS by means of a multiplicative factor defined by the variable ZSCALE. As discussed in Chapter 4 of (Hanna et al. 1982), σ_z is proportional z_0^p, where the exponent p can range from 0.10 to 0.25 and “larger values of the exponent p are applicable to shorter distances and rougher surfaces.” Because the Prairie Grass experiments on which the Pasquill-Gifford experiments were based were over grasslands with a roughness length estimated to be 3 cm, a typical empirical correction factor recommended by DOE guidance (DOE 2004) used to scale vertical dispersion uses the actual surface roughness divided by 3 cm to the 1/5th power. The standard multiplicative factor corresponding to a 10 cm surface roughness is $(10 / 3)^{0.2} = 1.3$, which is the value used in all of the base-case analyses presented in SOARCA. A roughness length that accounts for the forested area in the region may be estimated to be approximately 100 cm, resulting in a ZSCALE correction factor of 2.0. Use of this scaling factor is clearly appropriate for the Tadmor-Gur approximation, which is based on the Pasquill-Gifford curves derived from the Prairie Grass experiment. To evaluate the applicability of scaling factors to other diffusion parameterizations, staff examined the discussions in . Because the Briggs curves give very similar quantitative results to the Pasquill-Gifford curves at close ranges, conclude that it is appropriate to apply a ZSCALE factor to the Briggs open country values at distances of less than 10 km. Project staff chose a ZSCALE value of 2.0 with several considerations in mind:

- The discussion in (Napier et al. 2011) of the recommendation by (Pasquill 1976) that the correction should only be applied within a few kilometers of the release, coupled with the observation that at longer ranges where the plume is likely to be fully vertically mixed, the effect of the ZSCALE parameter is expected to be less significant, since the vertical dispersion is controlled by the mixing height rather than the sigma-z value.
- The potential for high doses is highest at close ranges. This area is characterized by a mix of buildings and forest with an estimated roughness length of 100 cm, resulting in a ZSCALE factor of 2.0.

This value is a source of uncertainty, and project staff recommends a ZSCALE range between 1 and 2.5 to account for the potential uncertainties associated with surface roughness effects near the site.

Adjustment of the crosswind plume dimensions to account for wind shifts that can occur at time intervals less than that of the recorded weather data can be handled in MACCS by use of a crosswind scaling factor YSCALE, which is constant for all distances. Staff considered use of the Regulatory Guide 1.145 plume meander model, which may be implemented by setting the value of MNDMOD to a value of “NEW.” The new MACCS plume meander is based on NUREG/CR-2260 (Snell and Jubach 1981) and Regulatory Guide 1.145 (NRC 1982a) and accounts for the observation that that the impact of plume meander is dependent on stability class and wind speed. This model is based on empirical data from field studies conducted at Rancho Seco (Start et al. 1977) and at the Experimental Organic Cooled Reactor test reactor building complex at the Idaho National Laboratory (Start et al. 1980). Review of these reports showed that the model developed in NUREG/CR-2260 uses meander factors to correct the

Pasquill-Gifford sigma-y values to account for plume meander and building wake effects. However, because the L3PRA, like SOARCA, did not use Pasquill-Gifford curves directly, but instead used the results of expert elicitations to formulate coefficients for the power-law formulation, staff concluded that the technical basis for use of the new meander model with diffusion parameters other than those approximating the Pasquill-Gifford curves was not appropriate, and therefore did not credit plume meander. This is consistent with the SOARCA practice, which set the value of the MNDMOD to OFF. Because the credit for meander diminishes beyond 800 m downwind, and approaches unity at longer distances, this change is not expected to have a significant impact on the results at this site, for which the site boundary is approximately 1200 m from the point of release, and the location of populated sectors generally much further.

3.3.2.6 *Deposition Modeling*

Dry deposition is modeled in MACCS using a source depletion method (Chamberlain 1953; Hosker 1974; Karlsson 1982) modified to allow treatment of a particle-size distribution and of capping of vertical expansion by an inversion lid. The source depletion method calculates the rate at which materials are deposited onto the ground as the product of the ground level (conventionally taken as 1 m) air concentration of the materials and the dry deposition velocity (see Equation 12.2 of [Sehmel 1984]) of those materials. This method makes use of the simplifying assumption that deposition onto the ground does not significantly affect the air concentration near the ground. This assumption allows the plume to be treated as Gaussian when deposition occurs. In the general case, with multiple aerosol sizes each with a different deposition velocity, the ground concentration is the sum over the set of aerosol sizes of the products of the time-integrated air concentrations and the deposition velocities. The material in each radionuclide class can be distributed among several particle-size groups (up to 20), with each class having a different distribution of material among the particle-size groups. The particle-size distribution of each radionuclide class is specified in the release description data (shown in Table A.1b, in this analysis). Because each particle size can deposit at a different rate, both the size distribution and the relative amounts of the radionuclide classes can vary with downwind distance.

The concentration of monodisperse aerosols at a location on the ground is the product of the integrated ground-level air concentration and the deposition velocity. It can be shown in Section 2.10.2 of (Jow et al. 1990) that the fraction of material f_{dry} in the plume at the beginning of the time period Δt that is not removed by dry deposition during the time period can be given by

$$f_{dry} = \frac{Q}{Q_0} = e^{-\frac{v_d \cdot \Delta t}{\overline{z}}}$$

where Q_0 is the amount of radioactive material transported into the spatial element, Q is the amount of radioactive material transported out of the element, v_d is the deposition velocity, Δt is the time that the plume segment takes to cross the spatial element, and $\overline{z}$ is the effective height of plume. The dry deposition velocity is a function of the degree of turbulence in the surface boundary layer of the atmosphere (which is affected by wind speed and surface

roughness) and particle size. The effect of surface roughness on deposition velocity has been characterized in NUREG/CR-7161 (Bixler et al. 2013) based on expert elicitation data from (Harper et al. 1997). The experts provided data for two wind speeds, 2 and 5 m/s, and for three terrain types, corresponding to meadow, forest, and urban terrains. NUREG/CR-7161, as revised in recent versions of MELMACCS, provides a set of correlations for estimating deposition velocity as a function of aerosol diameter, wind speed, surface roughness, and percentile representing degree of belief by the experts. The correlation has the form

$$\ln(v_d) = a + b \cdot ln(d_p) + c \cdot [ln(d_p)]^2 + d \cdot [ln(d_p)]^3 + e \cdot z_0 + f \cdot v$$

where d_p is the aerosol aerodynamic diameter (μm), z_0 is the surface roughness (m), and v is the mean wind speed (m/s). In this regression equation, surface roughnesses of 5, 100, and 50 cm were chosen to represent meadow, forest, and urban terrains, respectively. This correlation is valid for aerosol aerodynamic diameters up to about 20 μm and surface roughness up to about 100 cm. The coefficients of the correlation for the median value estimate are given in Table 3.3-4[15].

Table 3.3-4: Median value regression coefficients for dry deposition modeling

a	b	c	d	e	f
-2.964	0.992	0.19	-0.072	1.061	0.169

Based on these results, the formulation for the 50th percentile correlation is as follows:

$$\begin{aligned}\ln(v_d) &= -2.964 \\ &+0.992 \cdot ln(d_p) + 0.190 \cdot [ln(d_p)]^2 - 0.072 \cdot [ln(d_p)]^3 \\ &+1.061 \cdot z_0 \\ &+0.169 \cdot v\end{aligned}$$

where d_p, z_0, and v are defined as above.

To compute deposition velocities, wind speed was chosen to be 2.3 m/s, consistent with the mean wind speed and default weather. As discussed in Section 3.3.2.4, the surface roughness was estimated to be 100 cm due to the predominantly forested land cover. If d_p is greater than or equal to 20 μm, the calculation is switched to use gravitational settling to estimate the deposition velocity. If the value calculated using gravitational settling is less than the velocity calculated using the expert data at 20 μm, the velocity calculated uses the expert data at the cutoff diameter. Table 3.3-5 and Figure 3.3-1 show the dry deposition velocity values. While the model assumes that deposition velocity does not vary based on chemical properties, each

[15] The value of these coefficients may be viewed in the MelMACCS.ini file distributed with MelMACCS 2.01 and above.

chemical group has a different distribution of aerosol sizes estimated by MELCOR and therefore the modeling allows the deposition velocity behavior to be different for each chemical group.

Staff used the MelMACCS preprocessor code to generate the appropriate deposition velocities for use in the MACCS input. The following flags were used in the MelMACCS template file to generate the deposition velocity cards:

/Deposition_Velocity	Expert
/Surface	1
/Wind_Speed	2.3
/Quantile	0.5
/Cutoff_Diameter	20
/Disable_Deposition_Velocity	FALSE

The values generated by MelMACCS are given in Table 3.3-5. These results were verified by checking against the results of hand calculations and are in good agreement.

Table 3.3-5: Median dry deposition velocities (cm/s) for each of the 10 aerosol bins assuming a 100 cm roughness length and a 2.3 m/s wind speed

Bin Number	1	2	3	4	5	6	7	8	9	10
d_p (µm)	0.15	0.29	0.53	0.99	1.8	3.4	6.4	12	22	41
v_d (cm/s)	0.11	0.10	0.13	0.22	0.43	0.87	1.7	2.8	3.4	5.2

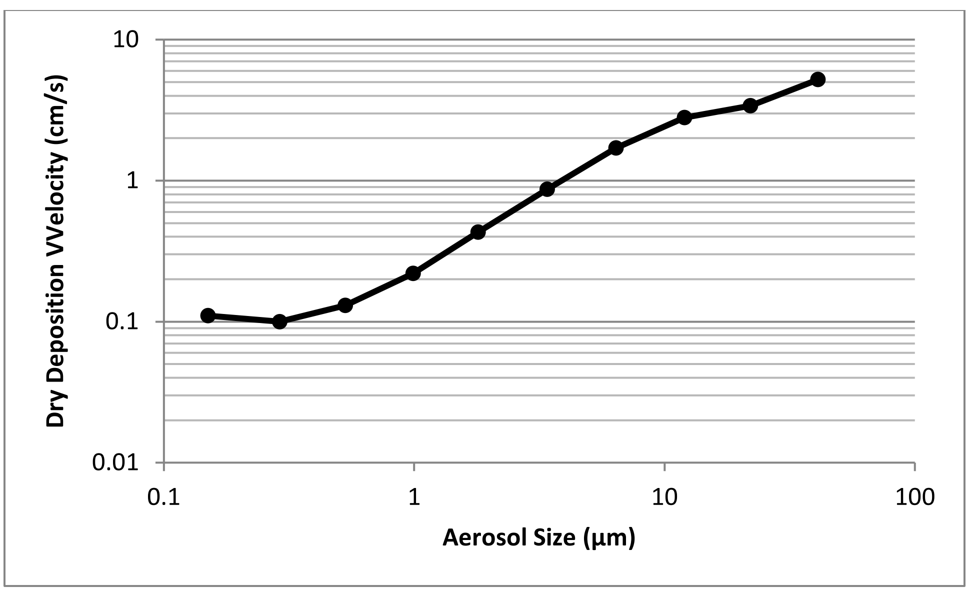

Figure 3.3-1: Median dry deposition velocities for each of the aerosol bins assuming a 100 cm roughness length and a 2.3 m/s wind speed

Unlike dry deposition, which is a continuous and relatively slow process, wet deposition is not continuous and can be quite rapid. Under heavy rains, wet deposition can rapidly deplete the plume. Even under light rains, the plume is depleted much faster than by dry deposition alone. The wet deposition process can produce concentrated deposits on the ground and create what is often referred to as a hot spot (i.e., an area of higher radioactivity than the surrounding areas). While rain occurs less than 10 percent of the time for most of the U.S., it can significantly affect consequence calculations when it does occur.

Wet deposition is treated as a function of both rain duration and rain intensity. MACCS treats the effect of wet deposition using a source depletion approach similar to the treatment of dry deposition by calculating the fraction of aerosol material in the segment at the beginning of the time period Δt that is not removed by wet deposition during the time period. The fraction f_{wet} that remains suspended after wet deposition is (Brenk and Vogt 1981):

$$f_{wet} = \frac{Q}{Q_0} = e^{-C_1 \cdot {I_r}^{C_2} \cdot \Delta t}$$

where Q_0 is the amount of radioactive material (Bq) transported into the spatial element, Q is the amount of radioactive material (Bq) transported out of the element, C_1 is the linear washout coefficient corresponding to the MACCS input variable CWASH1, Δt is the duration of precipitation (s) (taken in MACCS as the time(s) that the plume segment takes to cross the spatial element or the duration of rain, whichever is shorter), I_r is the intensity of precipitation (mm/hr), and C_2 is the exponential washout coefficient corresponding to the MACCS input variable CWASH2. As reported in (Sprung et al. 1990), (Brenk and Vogt 1981) recommended values of 1.2×10^{-5} s^{-1} and 0.5 for C1 and C2, respectively. Based on NRPB reviews (Jones 1986a,b), (Jow et al. 1990) used values of 9.5×10^{-5} s^{-1} and 0.8 for C1 and C2, respectively. For this analysis, the linear and exponential coefficients for washout (CWASH1 and CWASH2, respectively) were based on the values used in the SOARCA project, derived from expert elicitation data from (Harper et al. 1995). Bixler et al. (2013) provides a set of correlations based on the elicitations conducted in (Harper et al. 1995) for estimating wet deposition parameters as a function of aerosol diameter and percentile representing degree of belief by the experts. Based on these results, the best estimate for the 50th percentile correlation is as follows:

$$ln(C_1) = -10.875 + 1.6 \cdot ln(d_p) + 0.122 \cdot \left(ln(d_p)\right)^2 - 0.145 \cdot \left(ln(d_p)\right)^3$$

where d_p is the aerosol diameter in micrometers [µm]. This correlation is valid for aerosol diameters up to about 10 µm. Because C_1 and C_2 are correlated, (Bixler et al. 2013) recommended a single fixed value of 0.664 for C_2. Based on these results, Table 4-1 of (Bixler et al. 2013) estimated the median value of the linear washout coefficient C_1 to be 1.89×10^{-5} s^{-1} for a 1-µm particle and the value of the exponential coefficient C_2 to be 0.664, which was the value used in Table C.1 of SOARCA (SNL 2012a,b).

Table 3.3-6: Median wet deposition removal rate constants

Bin	1	2	3	4	5	6	7	8	9	10
d_p (μm)	0.15	0.29	0.53	0.99	1.8	3.4	6.4	12	22	41
C_1	3.8E-6	4.1E-6	7.5E-6	1.9E-5	4.9E-5	1.2E-4	2.2E-4	2.3E-4	1.4E-4	1.4E-4

To examine the potential range in this parameter as a function of particle size, the computed range for all particle-size bins are given in Table 3.3-6. As an aid in evaluating the significance of a representative value of C_1, the fraction of aerosols removed during one hour of low to moderate (2 mm/hr) rainfall estimated from the various studies is shown in Table 3.3-7.

Table 3.3-7: Comparison of estimated fractional removal during one hour of low to moderate rainfall

Study	Fraction
Brenk and Vogt (1981)	46% (C1=1.2E-4, C2=0.5)
Sprung et al. (1990)	45% (C1=9.5E-5, C2=0.8)
Harper et al. (1995)	1 µm: 20% (average of median value from experts B-G, ranging from 2-50%) 10 µm: 73% (average of median value from experts B-G, ranging from 21-92%)
Bixler et al. (2013)	1 µm: 10% (median value parameters: C1=1.89E-5, C2=0.664) 3 µm: 45% (median value parameters: C1=1.05E-4, C2=0.664) 10 µm: 75% (median value parameters: C1=2.45E-4, C2=0.664)

Unlike dry deposition velocity, MACCS does not allow wet deposition velocity parameters to be specified as a function of particle-size bins. To strike a balance between the low removal rate constants for submicrometer particles and the much more rapid removal from larger particles, this analysis follows the practice established in the SOARCA project of using the value derived from the 1-µm median value of 1.89×10^{-5} s^{-1} for the linear washout coefficient C_1 and 0.664 for the exponential coefficient C_2. As an alternative, an approach could be performed using the 3-µm parameters to give $C_1 = 1.05 \times 10^{-4}$, on the basis that the median particle size from a release is on the order of 3 µm. The wet deposition parameters are a source of uncertainty for which distributions are available and for which the effect of alternate particle-size assumptions could be examined parametrically.

3.3.3 MACCS Atmospheric Dispersion and Deposition Input Parameter Summary

A summary of the MACCS input parameters related to atmospheric dispersion and deposition is provided in Table 3.3-8.

Table 3.3-8: Summary of MACCS input parameters related to atmospheric dispersion and deposition

Variable	Description	Value	Source
IPLUME	Plume Model Dispersion Code	3	Section 3.3.2.1
OVRRID	Wind Rose Probability Override	.FALSE.	
NUMCOR	Number of Compass Sectors in the Grid	64	
NUMRAD	Number of Radial Spatial Intervals	35	
SPAEND	Radial distances for grid boundaries (km)	Table 3.3-1	
SIGYINIT	Initial Sigma-y (m)	Table 3.3-2	Section 3.3.2.2
SIGZINIT	Initial Sigma-z (m)	Table 3.3-2	
BUILDH	Building Height (m)	Table 3.3-2	Section 3.3.2.3
BRGSMD	Briggs Model Flag	IMPROVED	
PLMMOD	Flag for Plume Rise Input Option	DENSITY	
SCLCRW	Scaling Factor for Critical Wind Speed	1	
SCLADP	Scaling Factor for A-D Plume Rise	1	
SCLEFP	Scaling Factor for E-F Plume Rise	1	
DISPMD	Dispersion Model Flag	LRTIME	Section 3.3.2.5
CYSIGA	Linear Coefficient for sigma-y		
	Stability Class A	0.7507	
	Stability Class B	0.7507	
	Stability Class C	0.4063	
	Stability Class D	0.2779	
	Stability Class E	0.2158	
	Stability Class F	0.2158	
CYSIGB	Exponential Term for sigma-y		
	Stability Class A	0.866	
	Stability Class B	0.866	
	Stability Class C	0.865	
	Stability Class D	0.881	
	Stability Class E	0.866	
	Stability Class F	0.866	
CZSIGA	Linear Coefficient for sigma-z		
	Stability Class A	0.0361	
	Stability Class B	0.0361	
	Stability Class C	0.2036	
	Stability Class D	0.2636	
	Stability Class E	0.2463	
	Stability Class F	0.2463	
CZSIGB	Exponential Term for sigma-z		
	Stability Class A	1.277	
	Stability Class B	1.277	
	Stability Class C	0.859	
	Stability Class D	0.751	
	Stability Class E	0.619	
	Stability Class F	0.619	
YSCALE	Scale Factor for Horizontal Dispersion	1.0	
ZSCALE	Scale Factor for Vertical Dispersion	2.0	

Table 3.3-8: Summary of MACCS input parameters related to atmospheric dispersion and deposition (continued)

Variable	Description	Value	Source
CYDIST	Distance for switching to long-range dispersion model (m)	30,000	Section 3.3.2.5
CYCOEF	Coefficient for crosswind dispersion (m/s)	0.5	
MNDMOD	Plume Meander Model Flag	OFF	
DRYDEP	Dry Deposition Flag	Xe = .FALSE. Other groups = .TRUE.	Section 3.3.2.6
VDEPOS	Dry Deposition Velocities (m/sec)		
	Aerosol Bin 1	1.07E-03	
	Aerosol Bin 2	9.85E-04	
	Aerosol Bin 3	1.29E-03	
	Aerosol Bin 4	2.18E-03	
	Aerosol Bin 5	4.26E-03	
	Aerosol Bin 6	8.71E-03	
	Aerosol Bin 7	1.68E-02	
	Aerosol Bin 8	2.75E-02	
	Aerosol Bin 9	3.41E-02	
	Aerosol Bin 10	5.15E-02	
WETDEP	Wet Deposition Flag	Xe = .FALSE. Other groups = .TRUE	
CWASH1	Linear Coefficient for Washout	1.89E-05	
CWASH2	Exponential Term for Washout	0.664	
IDEBUG	Debug Switch for Extra Debugging Print	0	
NUCOUT	Radionuclide Used in Dispersion Print	Cs-137	

3.3.4 Identification and Discussion of Uncertainties Related to Atmospheric Dispersion and Deposition

There are a numbers of sources of uncertainty in the calculation. These are listed in Table 3.3-10 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.3-11 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.3-10. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS. Additional discussion of potential uncertainties, and approaches to evaluate them, are provided below.

As discussed in Section 2.1.2 of (Sprung et al. 1990), "selecting values for BUILDH and BUILDW may not be straightforward," because the degree of mixing would be affected by the level of ambient turbulence as well as the initial failure dimensions, which are uncertain. Furthermore, determining the height and, especially, the width of the building from which release occurs is not always straightforward. Because wake effects can persist for some

distance downwind of a structure ([EPA 1985] suggests a distance of 5 times the lesser of the width or height of the structure), a release from one part of the complex is likely to be affected by the wake generated by an adjacent structure. The reactor complex is comprised of a set of buildings and the heights and widths of the buildings in this complex vary. In addition, the complex is irregular in shape and the apparent width depends on the direction of the wind. In addition, there are alternate approaches to estimate the initial plume height and dimensions. As discussed in Section 5.10 of (Chanin and Young 1998a), an alternate approach to modeling building wake effects is provided in (Jones 1983), which recommends that the initial plume dimensions be assigned simply as one third of the height and width of the building, and the plume be released at an elevation of one third of the building height. The initial plume dimensions (and equivalently, the location of the virtual source) are a source of uncertainty, particularly in the near field, that has not been assessed in this analysis. The effect of these parameters was evaluated in NUREG/CR-6135 (Helton et al. 1995b; cf Table 4.1) for the Surry plant, which correlated building width and height, with building height being assigned a range of 15-35 m and a best estimate of 25 m, and building width being assigned a range of 15-100 m with a best estimate of 60 m. However, neither of these parameters were identified as a dominant contributor to uncertainty. This effect was also evaluated in the site environmental report, where the evaluation of an increase in the assumed building length (and hence initial plume sigma-y) showed a minor decrease in dose very near the release point and no noticeable effect on the 50-mile population dose.

The treatment of plume rise has the potential to be a contributor to uncertainty. Credit for buoyant plume rise, which can allow dispersion to occur overhead before the plume reaches ground level, could reduce ground level atmospheric concentrations (and therefore doses) close to the point of release. However, this may also result in a reduced level of dry deposition, allowing higher atmospheric concentrations at longer distances downwind. The net effect could therefore be complex, with offsetting effects. The effects of uncertainty in release elevation, which would be analogous to the effects of plume rise, were assessed in the licensee's environmental report, including sensitivities on the release elevation (with a change from ground level to the top of containment [modeled as 70 m in that analysis]). This change in release elevation resulted in decreased deposition close in, but a slightly (10 percent) higher population dose within 50 miles, as a result of the relatively less depleted plume. A sensitivity on plume heat (resulting in buoyant plume rise) resulted in similar effects, suggesting that some MACCS results could be somewhat sensitive to the assumed plume release height characteristics.

The values used for the diffusion parameters have the potential to be a significant contributor to uncertainty. The variables YSCALE and ZSCALE, which are modifiers on the plume dimensions, were found to be a dominant contributor to uncertainty in Section 7 of NUREG/CR-6135 (Helton et al. 1995b). Parameters related to transverse dispersion (CYSIGA and CZSIGA) were also found to be influential in SOARCA. NUREG-7161 provides tables of parameter values for the dispersion power law for the full range of uncertainties. These distributions were revisited in (SNL 2016) and, most recently, in Section 5.9.6 of (SNL 2019). The rationale for adjusting these parameter distributions is explained in that document and is not reproduced here. The result was to provide a recommendation that the uncertainty in dispersion coefficients be

represented by a log-triangular distribution for CYSIGA and CZSIGA characterized by the parameters provided in Table 3.3-9.

Table 3.3-9: Log-triangular values for diffusion parameters CYSIGA and CZSIGA

Class	CYSIGA (m)			CZSIGA (m)		
	Lower Bound	Mode	Upper Bound	Lower Bound	Mode	Upper Bound
A/B	0.3002	0.7507	1.8768	0.0144	0.0361	0.0903
C	0.1625	0.4063	1.0158	0.0814	0.2036	0.509
D	0.1112	0.2779	0.6948	0.1054	0.2636	0.659
E/F	0.0863	0.2158	0.5395	0.0985	0.2463	0.6158

Source: adapted from Tables 5-17 and 5-18 of (SNL 2019)

The degree to which these diffusion parameters should be adjusted for surface roughness (expected to impact vertical dispersion, i.e., implemented via ZSCALE) and plume meander (expected to impact transverse dispersion, i.e., implemented via YSCALE) is uncertain. Project staff recommends a range between 1 and 2.5 for ZSCALE to account for the potential uncertainties associated with surface roughness effects near the site. There is no specific project recommendation for quantitatively accounting for uncertainties in the treatment of plume meander, but alternate approaches (such as either the OLD or NEW meander model) available within MACCS could be used to investigate the sensitivity of results to different approaches.

Uncertainty in the treatment of both wet and dry deposition has the potential to be a significant source of uncertainty. Helton et al. (1995 a,b) found VDEPOS and (to a lesser extent) CWASH1 to be important parameters in the assessment of early and chronic exposure results. SNL (2016) found uncertainty in dry deposition velocity (VDEPOS), and to a lesser extent, wet deposition velocity (CWASH1), to be important sources of uncertainty for consequence results. Wet and dry deposition did not appear to be as significant for the analyses documented in (SNL 2019). Like the distributions for the diffusion parameters CYSIGA and CZSIGA, the deposition parameters from NUREG/CR-7161 were revisited in (SNL 2019). The distribution for VDEPOS derived in Section 5.9.2 of (SNL 2019) was site specific and is therefore not reproduced here. However, the general approach was to derive a distribution that was not as wide as those provided in NUREG-7161 by assuming that VDEPOS can be characterized by a triangular distribution with a mode equal to the median value estimate, and the lower and upper bounds chosen to be the mode divided and multiplied by the square root of 10, respectively. As discussed in Section 5.9.1 of (SNL 2019), the distribution for CWASH1 was estimated in a simpler manner, and was simply estimated as a log-uniform distribution between 1.6×10^{-6} s^{-1} and 1.6×10^{-4} s^{-1}.

Table 3.3-10: Uncertainties related to atmospheric dispersion and deposition

3.3.2.1 Wind Shift Treatment and Spatial Grid Definition	The resolution of the spatial grid results in the need to average across potential variability. The use of a polar grid means that grid elements become increasingly larger with distance from the source. This is not expected to be a significant source of uncertainty because the grid is defined with high resolution near the site.
3.3.2.2 Building Wake Effects	The effects of building wake on initial dispersion are complex and are not explicitly modeled and are instead modeled using a virtual source approach. Although wake effects would depend upon wind speed, wind direction, and turbulence, only a single value of the virtual source can be assigned for all realizations for a given source term. This is expected only to be significant at very close ranges, and given the low population near the site, is therefore not expected to be a significant contributor to uncertainty.
3.3.2.3 Plume Rise	The effect of plume rise was assessed as important in the NRC/CEC pilot study, but no further information was found on how it was addressed. The effect of this is expected to be most important for the estimate of early health effects, as vertical mixing would eventually overwhelm the effects of release height on ground-level concentration once the vertical plume dimensions were sufficiently large. The effect of this could be examined using sensitivity analysis on the MACCS variable SCLCRW.
3.3.2.4 Surface Roughness	Surface roughness is an approximation based on land cover. It varies spatially and could change over time due to variations in land use in the model domain. The effect of this could be examined by performing sensitivity analyses on ZSCALE and dry deposition velocity. Sensitivity analyses conducted as part of the SOARCA project (NUREG/CR-7110, Volume 1, and NUREG/CR-7009) indicate a modest impact on consequence results if surface roughness is varied on its own. However, considered in conjunction with dry deposition velocity, this impact could be greater (see Deposition Modeling discussion below).
3.3.2.5 Dispersion/ Turbulence Parameterizations	Multiple parameterizations of the dispersion coefficients exist for use with Gaussian models. These were the subject of elicitation in (Harper et al. 1995), and distributions for these are developed in (Bixler et al. 2013). In addition, as discussed in the text, alternate parameters for the power-law representation of the dispersion coefficients have been identified in literature reviews. The effect of alternate diffusion parameters could lead to changes in the estimates of air concentration and ground deposition. This is expected to be a significant source of uncertainty.

Table 3.3-10: Uncertainties related to atmospheric dispersion and deposition (continued)

	Use of a Gaussian plume segment model does not capture the dispersion associated with changes in the windfield or the turbulent dispersion over time in the horizontal and vertical direction. This is conceptually similar to the uncertainty identified earlier related to the use of observational data from only a single weather station, which is an assumption used to derive Gaussian plume-type models. This could be a significant source of uncertainty. The effect of this uncertainty could be evaluated using analyses of benchmark analyses against alternate codes that do capture such effects, such as was conducted in (Molenkamp et al. 2004). The effect of the higher fidelity models resulted in a difference in air concentration and ground deposition levels within a factor of approximately 2 out to distances of about 100 miles.
	The Gaussian plume segment model does not address topographic or geographic effects on atmospheric dispersion. Local topographic effects include phenomena such as land/sea breeze, slope or valley winds, thermal internal boundary layers, flow over hills, etc. Because the terrain surrounding the site is relatively flat with gently rolling hills, these effects are not expected to be significant. It should be noted that the potential effect of the bluff overlooking the river on which the site sits, has not been explicitly evaluated. However, the land across the river in that direction is a restricted access facility.
3.3.2.6 Deposition Modeling	Use of a single deposition velocity for all weather trials does not explicitly account for more recent approaches to deposition modeling (i.e., resistance layer models) that can address deposition as a function of wind speed, turbulence, chemical form, etc. Deposition velocities are expected to be a significant source of uncertainty. These effects are implicitly included in the elicitations documented in (Harper et al. 1995), such that the abstraction documented in (Bixler et al. 2013) does account for stability, wind speed, and surface roughness; however, a single representative value must be identified. The effect of this uncertainty could be evaluated using benchmark analyses against alternate codes that do capture such effects.
	Wet deposition models in MACCS use only a single coefficient and do not account for the effectiveness of precipitation scavenging associated with different particle sizes, chemical forms, precipitation types (i.e., rain versus snow, fog-water deposition, etc.), washout versus rainout, etc. The uncertainty in wet deposition models was evaluated in (Harper et al. 1995) and distributions for use in MACCS have been developed in (Bixler et al. 2013). Wet deposition could be a significant source of uncertainty.
	The form of deposition (i.e., wet versus dry) will affect both the initial distribution of deposited material (i.e., within soil column, on pavement, on roofs, into drains, etc.) and the rate at which it weathers. This affects both the initial dose from external radiation, as the distribution of materials will determine how much attenuation occurs between the deposited material and a human receptor, and the rate at which the material weathers, thereby reducing the dose rates. The effect of these factors are discussed in NUREG/CR-6526. This could be a significant source of uncertainty.

Table 3.3-11: Potential sensitivity analyses to address uncertainties related to atmospheric dispersion and deposition

Analysis	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
AT_1	Examine effect of building wake effects on initial dispersion	SIGYINIT, SIGZINIT recalculated using alternate structure dimensions or alternate estimation methods	Potential change in outputs characterized by threshold-type results sensitive to high doses at close distances; less impact expected where travel distance is much larger than virtual source distance.	Cyclic File Set
AT_2	Examine influence of plume rise on near-field results by suppressing plume rise	SCLCRW	Limited plume rise expected to increase threshold-type results sensitive to high doses	Cyclic File Set
AT_3	Examine uncertainty associated with plume rise parameters	SCLADP, SCLEFP	Limited plume rise expected to increase threshold-type results sensitive to high doses	Cyclic File Set
AT_4	Examine uncertainty in diffusion parameters	CYSIGA, CYSIGB, CZSIGA, CZSIGB	Results could be higher or lower depending upon specific result. Increased crosswind dispersion could reduce centerline doses, but increase the geographic extent of contamination. Increased vertical dispersion could increase ground level concentration for elevated releases, but decrease ground level concentration for ground level releases.	Cyclic File Set

Table 3.3-11: Potential sensitivity analyses to address uncertainties related to atmospheric dispersion and deposition (continued)

Analysis	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
AT_5	Examine effect of differentiating stable weather categories E/F	CYSIGA, CYSIGB, CZSIGA, CZSIGB based on Tadmor-Gur power-law curves or use of dispersion lookup table based on alternate parameterizations	Potential increase in outputs sensitive to tails of weather distribution (e.g., early health effects)	Cyclic File Set or Alternate Input Decks
AT_6	Examine effect of surface roughness on vertical dispersion	ZSCALE	Increased vertical dispersion could increase ground level concentration for elevated releases, but decrease ground level concentration for ground level releases	Cyclic File Set
AT_7	Increased or decreased dry deposition velocity	VDEPOS recalculated using alternate percentiles for deposition velocity	Higher deposition projected to lead to higher impacts close in offset by lower impacts at further distances	Cyclic File Set
AT_8	Examine effect of surface roughness or wind speed on deposition velocity	VDEPOS recalculated using alternate surface roughness and wind speeds	Higher deposition projected to lead to higher impacts close in offset by lower impacts at further distances	Cyclic File Set
AT_9	Examine effect of uncertainties in wet deposition	CWASH1, CWASH2 recalculated using alternate particle sizes and/or percentiles	Higher deposition projected to lead to higher impacts close in offset by lower impacts at further distances	Cyclic File Set

3.4 Protective Action Parameters and Other Site Data (PA) and Economic Factors (EC)

3.4.1 Assumptions and Known Limitations

- Site-specific population data is based on 2010 census data, and extrapolated forward to the project base year of 2015. Individuals are assumed to be located at their place of residence as represented by the centroids of the census blocks used to develop population estimates.
- A current code limitation is that MACCS estimates the long-term population distribution based on the sum of the individual early-phase cohorts. Although early-phase cohorts may be assigned to specific geographic locations based on their daytime locations rather than their residential locations, these cohorts are treated as residential for purposes of estimating long-term effects, such as long-term exposure and economic costs.
- Land use data (land/water fraction, fraction of land devoted to farming, etc.) and land value data are based on information from the Bureau of Economic Analysis reflected in the databases supplied with SECPOP 4.3.0 and escalated to the project base year of 2015.
- The economic consequences considered are limited to those calculated in the MACCS code. Other costs, such as costs for replacement power, onsite cleanup, or costs of medical care, are not addressed in this analysis.
- The restricted access industrial facility staff are modeled as members of the public for purposes of estimating per-capita wealth; that is, the costs associated with contamination of those grid elements will assume that the per-capita wealth is the same as that of members of the general public in the surrounding area. This ensures that economic costs associated with the contamination of the area where the industrial facility is located will be computed. This approach captures significant costs for the area, but may not fully capture the costs of interdicting the industrial complex.
- There is only one small private school within the emergency planning zone (EPZ), but there are many schools within 15 miles of the EPZ in the vicinity of the county seat. For sequences with a General Emergency (GE) projected shortly after Site Area Emergency (SAE), these schools are modeled as evacuating upon an SAE to facilitate use of the school facilities as shelters for EPZ evacuees. For sequences with longer delays between an SAE and GE, it is assumed that schools will be dismissed normally prior to a GE and would not be reopened, and no separate school population is therefore modeled for these sequences.
- Geographically specific per-capita daily costs for meals and lodging are estimated using published Federal per-diem rates for the nearest large metropolitan area.
- Estimates for per-capita wealth are adjusted using an inflation factor based on Bureau of Labor and Statistics (BLS) consumer price index (CPI) estimates.
- Protective actions include sheltering followed by evacuation, temporary or permanent relocation of individuals from areas of high projected doses, food and water interdiction, and decontamination.
- Dose projections are assumed to be available to support protective action decisions.
- MACCS evaluates the need for protective actions based on the results of dose calculations that credit shielding factors. This is a code limitation that is expected to be mildly

conservative with respect to doses and health effects, because it will result in a lesser extent of protective actions than may otherwise be taken.

- It is assumed that the initiating events do not cause damage at the nearby industrial facility that would require competing offsite response resources.
- Evacuation modeling considers staged evacuations and uses site-specific evacuation time estimates (ETEs). Protective actions are assumed to be expanded beyond the EPZ based on dose projections and Environmental Protection Agency (EPA) protective action guidelines (PAGs). This is consistent with the site protective action recommendation (PAR) procedure, which includes steps for determining guidance for PARs beyond the EPZ. For sequences with expanded protective actions, a mandatory evacuation order of the population within either 10-15 or 10-20 miles is assumed to occur after the decision to evacuate the EPZ.
- The current MACCS approach to evacuation model does not account for changes in evacuating timing associated with seasonal or diurnal variability. The ETEs are based on the timings for a normal winter workday. This will include schools in session and employees at work. A winter workday was selected for the response scenarios because it presents several challenges to emergency-response implementation, including evacuating while residents are at work and mobilizing buses to evacuate schoolchildren.
- It is assumed that all conditions involving a GE will result in an order to evacuate the full 10-mile EPZ, rather than a shorter 2- or 5-mile radius.
- For purposes of determining when evacuation may be expanded beyond the EPZ, failure or bypass of the containment leading to a large release is assumed to be identified no later than 1 hour after failure.
- For estimating early-phase relocation times, the time needed to identify areas subject to evacuation following plume arrival is assumed to be 4 hours, since field survey teams would be dispatched early in the event and would be guided by dose projection and meteorological information to facilitate rapid identification of hotspots.
- MACCS assumes that the non-evacuating cohort is subject to dose-dependent early phase relocation. MACCS does not apply dose-dependent early phase relocation to evacuating cohorts. Because only a single non-evacuating cohort (comprising individuals inside and outside the evacuation zone) is modeled, a single early-phase relocation time is assumed to be applicable both to individuals within the official evacuation zone, as well as individuals outside the official evacuation zone.
- A shadow evacuation for those that are not directed to evacuate, but are likely to evacuate anyway, is included. Any shadow evacuation is assumed to occur in a circular fashion, even if the general public were directed to evacuate following a keyhole concept.
- The dose criterion for the required decontamination after a severe accident is uncertain. No long-term land cleanup goal or level currently exists. The current state of practice is to model decontamination to the level of meeting the habitability criteria as defined by the intermediate-phase PAGs. The use of the EPA intermediate-phase PAGs (2 rem in the year of the accident and 500 mrem in subsequent years) is assumed as a surrogate for decisions on cleanup and reoccupation.

- Food/land interdiction and relocation are modeled based on projected dose levels that are inferred based on EPA and Food and Drug Administration (FDA) guidance. Areas with projected food doses above these levels are assumed to be interdicted.
- Decontamination is assumed to be complete within one year after the end of the intermediate phase (i.e., all cleanup is assumed to be completed within 2 years after the accident occurs).
- The MACCS cost model is assumed to adequately estimate the offsite costs arising from a reactor accident.

3.4.2 Technical Discussion

Recommendations for protective action parameters and economic factor information have been developed for the L3PRA project in a supporting report prepared by Sandia National Laboratories (SNL). Section 3.4 is adapted from and incorporates material from that report.

Following an accident at a nuclear power plant, protective actions are undertaken to reduce the potential for onsite and offsite consequences. Emergency-response programs are in place to assure that prompt and effective actions can be taken to protect the public (NRC 1980). These protective actions are identified in site-specific emergency planning documentation and State and local emergency plans, which are developed, tested, evaluated, and established as defense in depth. Emergency plans escalate response activities following a classification scheme based on emergency action levels (EALs). Preplanned actions are implemented at each classification level, including Notification of Unusual Event, Alert, SAE, and GE. Public protective actions are required at the GE level, but offsite response organization (ORO) plans commonly include precautionary protective actions at the SAE level, and sometimes at the Alert level. EPA (2013) describes three phases of the response following an accident. During the early phase, which may last from days to weeks, precautionary measures (e.g., sheltering or evacuation) may be undertaken, and individuals may be relocated from areas where doses are projected to exceed PAGs. During the intermediate phase, which begins after the source and releases have been brought under control, and which may last from weeks to a year, individuals may be relocated and contaminated foods may be interdicted. The late (or recovery) phase, in which recovery actions to reduce radiation levels in the environment to acceptable levels are undertaken, may extend from months to years. Actions during the late phase may involve decontamination and/or temporary interdiction of contaminated land, or condemnation of contaminated areas and disposal or interdiction of contaminated crops.

In MACCS, the doses received during the early phase are modeled by the EARLY module. The doses account for the movement of each plume segment and for early protective actions. Doses received during the intermediate and late phases are modeled in the CHRONC module. The CHRONC module also provides estimates of the economic impacts resulting from the protective actions taken to reduce exposure. MACCS employs a cost-based evaluation of economic impacts associated with protective actions to reduce dose that includes the following (Jow et al. 1990):

- Temporary evacuation and relocation costs, including food, lodging, and lost income for people who are evacuated or relocated during the emergency or intermediate phases
- Permanent relocation costs
- Decontamination costs for property that can be returned to use
- Lost return on investments from properties that are temporarily interdicted
- Depreciation of temporarily interdicted property
- The value of farmland and property that is permanently interdicted (condemned)
- Economic losses for milk and crops destroyed or not grown[16]

Modeling of these protective actions in the L3PRA project is based on the site-specific emergency planning documentation and state and local emergency plans.

The exposure of the population is a function of how long they are at a particular location and what kind of activity they are engaged in. Because the potential exposure locations and individual activities can be highly spatially and temporally variable during the early phase, MACCS allows the user to define distinct cohorts, representing discrete segments of the population that have different response characteristics affecting their exposure. As the early-phase protective action area expands beyond the EPZ, additional cohorts can be added. Although up to 20 distinct cohorts can be defined in MACCS, there is diminishing value in establishing a large number of cohorts because the response characteristics begin to overlap within the evacuation period and the effects on different cohorts become indistinguishable.

The offsite populations modeled in MACCS typically include members of the general public, as well as special populations such as schools, transient workers, or inmates at prisons. Unless otherwise specified, members of the general public are assumed to be located at their place of residence as defined by Census data, and are divided into groups based on their evacuation behavior, that is, those who:

- evacuate in accordance with official evacuation orders (evacuees)
- evacuate voluntarily without receiving official evacuation orders (shadow evacuees)
- do not evacuate, either because they fail to comply with an official evacuation order or because they are not subject to official evacuation orders due to their distance from the site (non-evacuees)

A shadow evacuation occurs when people outside an officially declared evacuation zone evacuate without having been instructed to do so. Shadow evacuations are considered because the additional traffic generated has the potential to impede an evacuation of the EPZ and because shadow evacuees represent members of the public who have left the area early and would not receive a dose. In addition to members of the general public who are assumed to be

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[16] The inclusion of both lost milk and crop sales and loss of use of farm property in the year of the accident may be considered double counting. State of practice is to include both categories in the summation of economic costs, but this practice may be reconsidered. Because these values are reported separately, the potential impact of this assumption can be evaluated by estimating the fraction of total costs associated with lost milk and crop sales.

located at their place of residence, special populations can also be defined and located based on their normal daytime location, which may be different from their place of residence. If such populations are included, care should be taken to ensure that they are not double-counted. Special populations may also be included in official evacuation or sheltering orders, but the timing of their movement may differ from that of the general population.

The ETE used in this analysis selected a normal winter workday as the base case for all analyses. A winter workday was selected for the response scenarios because it presents several challenges to emergency-response implementation, including evacuating while residents are at work and mobilizing buses to evacuate schoolchildren. There is only one small private school within the EPZ, but there are many schools within 15 miles of the site in the vicinity of the county seat. These schools are modeled as evacuating for selected sequences to facilitate use of the school facilities as shelters for EPZ evacuees. It should be noted that although the winter workday was selected as the base case for all analyses, some sequences were characterized by a significant delay before the major release. In those cases, it was assumed that the schools were closed by the time of the evacuation orders, and therefore students would mobilize and evacuate on the same timeline as the rest of the general public.

Although multiple source terms are possible, the timing for many source terms can be similar. This allows the EP model scenarios to be represented by a smaller set of EP timelines. In the L3PRA project, five EP model templates are defined based upon the distance to which early-phase protective actions are expected to be needed and characteristics of how the accident is expected to progress. In addition to the early-phase cohorts defined in these models, MACCS considers a single cohort for the late phase.

The exposure pathways considered during the emergency-phase period are cloudshine, groundshine, and direct and resuspension inhalation. Mitigative actions can be specified for the emergency phase, such as evacuation, sheltering, and relocation based on dose projections. The exposure pathways for the long-term phase are groundshine, resuspension inhalation, and food and water ingestion. This analysis considered two ingestion pathways, as modeled by MACCS. These include ingestion of contaminated food as a result of deposition of airborne radionuclides on food producing areas, and ingestion of contaminated water as a result of direct deposition and wash off of deposited radioactivity into surface water bodies that serve as a source of drinking water. Both pathways are only considered during the long-term phase, and both are computed only for collective effects purposes – that is, these pathways do not contribute to estimates of individual health risk. Interdiction of agricultural products may also give rise to economic effects based on the value of the interdicted agricultural products.

3.4.2.1 *Site Demographic Characteristics (Site File Development)*

MACCS can assign spatially uniform population and economic data or read spatially variable population and economic data from a site file. This is controlled by the MACCS variable POPFLG. When this variable is set to FILE, MACCS reads population data from a site file. In this analysis, census residential information and other demographic information was used to define a base-case site file, which was then postprocessed to yield SUMPOP site files to model

different evacuation scenarios. The process is summarized here. The site file used by MACCS is a formatted text file, as described in Appendix A3 of (Chanin and Young 1998a). For this analysis, an updated version (4.3.0) of the SecPop code (Bixler et al. 2003) was used to generate the base-case site file, and then a postprocessor script was developed to generate SUMPOP formatted site files containing the population for each cohort. The process involves developing the inputs required to generate a site file in SecPop and then manually adjusting the site file as needed. The steps used in this analysis are as follows:

1. Identify inputs to SecPop:
   - Identify location of plant
   - Determine project base year and the default population and economic escalators
   - Define spatial grid
   - Determine radius of exclusion area boundary (EAB)
2. Develop site file using SecPop 4.3.0
3. Manually adjust site file:
   - Adjust population to account for county-specific population growth
   - Verify close-in population distribution
   - Adjust population distribution to account for special populations
   - Adjust remaining parameters
4. Assign site file population to individual cohorts for use in SUMPOP site files
   - Identify the early-phase cohorts to be used in the analysis
   - Develop the POP_DIST matrix to apportion the base-case site file population into individual early-phase cohorts on a geographically explicit basis
   - Verify proper assignment of population to individual cohorts

Development of site file (Steps 1-3)

SecPop requires specification of the site location so that the population distribution relative to that point can be computed. The origin of the site file was set to the geographic location of the Unit 1 containment.

The project base year was selected to be 2015. Since the base year was prior to the current year, a direct estimate of the escalator was computed. For reference, if the project base year were in the future (as it was during development of the original version of the site file), an annualized rate can be determined from current data and projected forward to the desired year. The national population escalator was determined using U.S. Census data current population estimates for 2015 available at

https://www.census.gov/popest/data/national/totals/2015/files/NST-EST2015-alldata.csv

Since the SecPop database was based on 2010 data and the base year is 2015, the national population escalator was determined as follows:

United States CENSUS2010POP: 308,745,538

United States POPESTIMATE2015: 321,418,820

Population Multiplier = 1.04104766, rounded to 1.04

The economic escalator was obtained from the BLS inflation calculator. The economic database in the version of SecPop used to generate the initial site file was from 2007, so 2007 was used as the initial year. The BLS inflation calculator (http://data.bls.gov/cgi-bin/cpicalc.pl?cost1=1.00&year1=2007&year2=2015) yielded an escalator of 1.14. This was checked against an escalator derived from the core CPI using information from https://data.bls.gov/timeseries/CUSR0000SA0L1E. This CPI series excludes food and energy and which therefore may be somewhat less volatile. The escalator derived from the core CPI from 2007 to 2015 was determined to be 1.15, or less than a 1 percent difference.

The EAB is an irregular polygon but must be specified in SecPop as a fixed radius. The minimum distance from Unit 1 to the EAB is approximately 3600 ft. Per the site plan, this is to the east in the direction of the restricted access industrial complex. Based on that information and the definition of the spatial grid above, the minimum distance to the site boundary is shown in Table 3.4-1. In addition, the radial index of the MACCS grid corresponding to the site boundary, and the distance to the endpoint of that grid element, is also shown in Table 3.4-1. The radius for the EAB was therefore set at the 0.75-mile (1.21-km) ring (Rings 1-3).

Table 3.4-1: Location of exclusion area boundary

Sector	Distance (m)	Distance (km)	Radial Index of EAB region	Outer radius of spatial interval corresponding to EAB Radial Index (km)
N	1344	1.344	3	1.207
NNE	1097	1.097	2	0.8047
NE	1097	1.097	2	0.8047
ENE	1097	1.097	2	0.8047
E	1369	1.369	3	1.207
ESE	1817	1.817	4	1.6093
SE	1866	1.866	4	1.6093
SSE	1773	1.773	4	1.6093
S	1692	1.692	4	1.6093
SSW	1680	1.68	4	1.6093
SW	1462	1.462	3	1.207
WSW	1462	1.462	3	1.207
W	1462	1.462	3	1.207

Table 3.4-1: Location of exclusion area boundary (continued)

Sector	Distance (m)	Distance (km)	Radial Index of EAB region	Outer radius of spatial interval corresponding to EAB Radial Index (km)
WNW	1649	1.649	4	1.6093
NW	2240	2.24	4	1.6093
NNW	1804	1.804	4	1.6093
Average	1556.94	1.56	3	1.207
Median	1555.5	1.6	3	1.207

SecPop 4.3.0 was used to develop the site file. The values for the site location, population and economic multipliers, and spatial grid were entered, and the EAB was assigned. To assign economic regions, exact regions (which result in a unique mix for each grid element) were assigned out to a distance of 10 miles, and radial regions were assigned to a distance of 100 miles. This resulted in 81 regions, which is less than the 99 allowed. For the area beyond 100 miles, a uniform economic region was assigned to represent the weighted average of the entire area beyond 100 miles.[17] In addition, although parameter values from the original MACCS sample problem related to the original MACCS food-chain model are contained within the site file generated by SecPop, there is no provision for altering these in SecPop. However, since the new MACCS food model was selected in this analysis, these parameters are not used and were not adjusted. The only other parameters requiring adjustment were the watershed parameters. Watershed index 2 was added at distances greater than 100 miles to indicate the regions occupied by the offshore (saltwater) locations.

After development of the initial site file, manual adjustment was performed to correct economic regions, apply county-specific population multipliers, and allocate special populations. Inspection of the resulting economic region assignment showed a large number of grid elements that did not contain a census block centroid (Region 3). Approximately 60 percent of the grid elements between rings 4 and 15 (0.75 miles to 10 miles) were assigned to Region 3, and 14 percent of the grid elements between 10 and 50 miles (albeit primarily within 15 miles) were assigned to Region 3. All grid elements within 15 miles that contained Region 3 were reassigned to the economic region of the adjacent (in the radially outward direction) grid element. In some cases, this resulted in a number of contiguous grid elements being designated as water. These grid elements were manually reassigned to economic region corresponding to the county where the element is located.

To adjust for county-specific population multipliers, data on current population estimates at the county level is available from https://www.census.gov/popest/data/national/totals/2015/files/CO-EST2015-alldata.csv. This datafile was downloaded and modified by adding a column to provide a unique county-state designator to allow use in a lookup table. The REACCT extended site file

[17] It should be noted that the analysis does not report results at distances greater than 100 miles, and therefore the assignment of economic regions beyond 100 miles should have no effect on reported results.

contains data for each grid element on the fractional population contribution from each county. A lookup table was constructed to read the population for each county in the REACCT extended file and divide it by the 2015 population of that county from the census county-level current population estimate, yielding a county-specific multiplier. For each entry in the REACCT extended site file within a 100-mile radius, the estimated 2015 population from each county in each grid element was computed by multiplying the 2010 population of the county, the population multiplier for each county, and the relative population fraction for each grid element/county pair. An EXCEL pivot table was constructed to provide the summed population for each grid element arranged in a matrix by row and sector. The SECPOP extended site file population was imported into EXCEL to serve as a base file. The final combined population for each grid element was developed by using the county-level adjusted population within 100 miles and the base-case population (which used the national multiplier determined in Step 3) for the grid elements outside of 100 miles.

SecPop population data is defined at the census block level with the population assigned to the centroid of the census block. Because the centroid may not correspond to the actual population locations within a census block, this can result in a discrepancy between the actual population location and that reported by SecPop. Because the EAB is an irregular polygon with some areas at longer distances than the selected radius, the resulting distribution was checked to ensure that no offsite populations were located within the actual EAB area. The sectors corresponding to the actual EAB areas were determined by computing the sector-specific distance to the site boundary and identifying, for each of the 16 sectors, the ring number that would fall completely within the EAB. No population lay within these blocks.

A map of the census blocks in the vicinity of the site was obtained, together with the block level census interactive population maps at http://www.census.gov/2010census/popmap/, and compared to visual images from Google Maps to check the reasonableness of the population distributions by seeing whether indications of the presence or absence of residential structures was consistent with the reported distribution. The census block map for this area shows that the census blocks surrounding the site can be relatively large. Because SecPop locates all of the population of a census block at the centroid of that block, this can result in a displacement of the population relative to its actual location. The spot check showed that the SecPop file results were reasonably consistent with evidence of residential structures. One census block encompassed areas north of the site that appear to be within the EAB as well as areas to the southeast of the site that appear to be outside the EAB. SecPop placed this population to the northwest of the site (Sector 57, Ring 5). Review of aerial images suggest evidence of structures at this approximate location and this assignment was considered reasonable. Another census block lies to the west of the site. SecPop placed this population to the west at Sector 49, Ring 7, which is somewhat more distant than the only structures visible in the area, which appear to be closer to the site boundary. However, in the absence of clear indications of actual population location, the site file was not modified to relocate this population closer to the site.

A review of special populations around the site suggested that the only special population requiring geographically explicit modeling was the industrial facility worker population of 11,000 located across the river at the restricted access industrial facility. The process used to adjust the

population distribution for this industrial cohort is, in general, extensible to any geographically explicit population. The process involves:

- identifying where the special population should be located
- placing the population at the designated location
- removing (if necessary) population from other grid elements to avoid double counting of populations

The industrial employee population was reallocated to areas within the industrial complex based on data on the distribution of employees by specific areas within the complex. To eliminate double counting, the 2015 county of residence for these employees was obtained. This data was used to construct a lookup table that would compute a county-specific multiplier (i.e., the county-specific employee population was subtracted from the total county population to determine the fraction of non-facility employees residing in the county). This multiplier was added to the county-specific multiplier to further reduce the population of those counties, as facility employees were relocated to specific locations within the facility area.

The resulting base-case site file was named [*SITE*]_2017_10_13.inp. An intermediate version was used to verify proper operation of this file by re-execution of R00 Case 5D using WinMACCS 3.9.8. The outputs were compared to verify that results that did not depend upon the population distribution (e.g., early fatality range, peak dose on spatial grid) were unchanged, and that other changes were consistent with the modified population distribution. The resulting cumulative population distribution as a function of distance from the site out to a distance of 100 miles is shown in Table 3.4-2.

Assignment of populations to specific emergency-response cohorts

The EPZ area is split between two neighboring states. Each state has emergency planning and protective action responsibilities. There are very few EPZ residents across the river, where the restricted access industrial facility encompasses most of the EPZ. This restricted access complex encompasses most of the north and easterly portions of the EPZ. That complex is responsible for emergency-response actions on its own property in the event of an emergency at the site. The restricted access industrial complex covers 310 square miles that includes 126 miles of paved road and 1,100 miles of secondary roads. The area around the complex is rural and sparsely populated with relatively flat terrain consisting mostly of farmland and forested areas. The evacuation routes within the EPZ are made up of state highways and local roadways. There are no interstate highways or traffic signals within the EPZ and only a small number of single span bridges and roadway crossings over creeks and drainage areas. As the distance increases away from the plant, the roadway infrastructure increases, particularly in the northerly direction.

The transient population is addressed in the site evacuation time estimate and was reviewed by SNL for applicability to this analysis. The U.S. Census Bureau's Longitudinal Employer-Household Dynamics interactive website was used to compute the number of people

commuting to work on a daily basis. This provided a method to determine employment within the areas without double counting people that are already included as permanent residents. The transient population within the plume exposure pathway EPZ includes (in addition to persons employed at the site) staff at the restricted access industrial complex, and a small number of recreational hunters and fishermen. The employees of the restricted access industrial complex are treated explicitly in the calculation. The small number of recreational transients was not modeled separately because they are mostly weekend hunters and represent a population that is small relative to the population of the EPZ (a few hundred on weekends during the fall hunting season, and about half that at other times of the year). The total transient population in the analysis area is about the same as the population that lives in the area but commutes to jobs outside of the area. When transients are included in MACCS, the code treats them as though they are residents by applying all cost factors attributable to residents. This review found that those commuters entering the area were about equal to those exiting the area; therefore, a separate cohort was not developed.

General Public Evacuees

The process of notification, mobilization, and evacuation may be represented as curves that are relatively steep at the beginning and tend to flatten as the last members of the public exit the area, as shown in Figure 3.4-1.

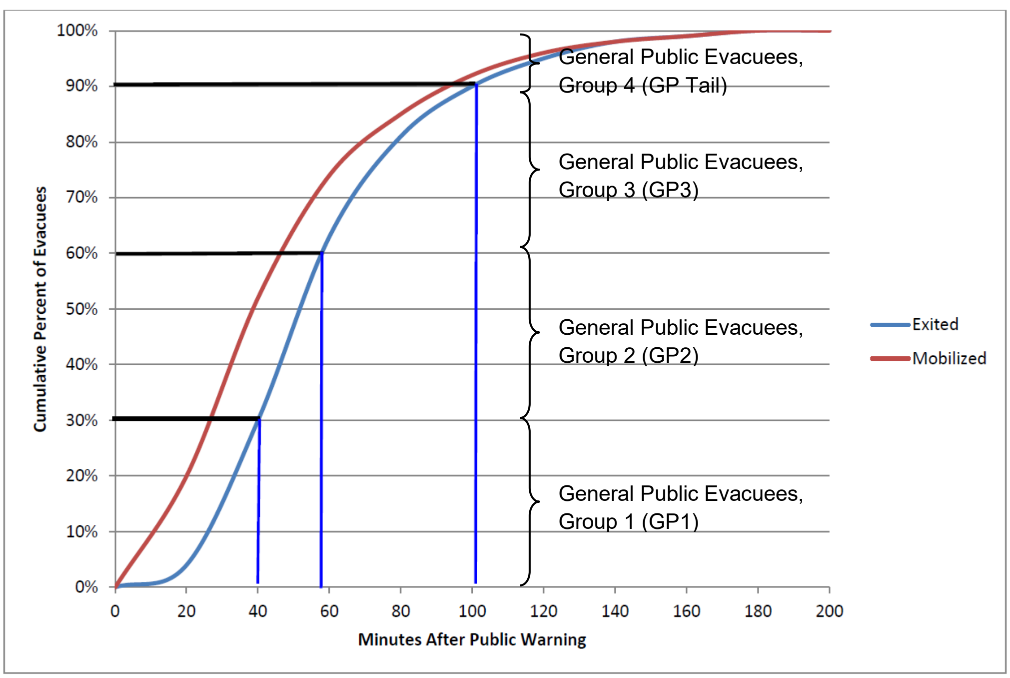

Figure 3.4-1: ETE mobilization and evacuation curve showing the 30, 60, 90 and 100 percent evacuation of the full 0–10 mile EPZ
Source: (adapted from site evacuation time estimate report).

Notification involves the time needed for the public to be notified and understand the evacuation order. Mobilization includes the subsequent preparatory activities preceding evacuation. The flat

part of the curve to the far right typically represents the last 10 percent of the population and is identified as the evacuation tail (Wolshon et al. 2010). Because a traffic loading curve cannot be input directly into MACCS, the distribution is approximated by assigning multiple cohorts with different evacuation timings to represent the general public as described in NUREG/CR-7160 (Sullivan et al. 2013). The segments are defined in this analysis as the first 30 percent, up to 60 percent, up to 90 percent, and the final 10 percent, as shown in Figure 3.4-3. This results in four cohorts to represent the general public who evacuate according to official orders. Because evacuation orders would be issued in a staggered fashion, with individuals closest to the site being evacuated first, there are three radial intervals that are considered in developing cohorts. The EPZ, which is approximately up to 10 miles from the site, would be evacuated first. If necessary, the evacuation could be expanded incrementally to 15 or 20 miles. This results in a maximum of 12 cohorts representing the spatial and temporal dependence of members of the general public who evacuate according to official orders, depending upon the extent of expanded evacuation necessary.

Shadow evacuees

A shadow evacuation occurs when people outside of any officially declared evacuation zone leave without having been instructed to do so. A shadow evacuation typically begins when a large scale evacuation is ordered (Dotson and Jones 2005). Shadow evacuations are considered because the additional traffic generated has the potential to impede an evacuation of the EPZ and because shadow evacuees represent members of the public who have left the area early and would not receive dose during the emergency phase. Although MACCS does not have the ability to explicitly model the effect of a shadow evacuation on the clearance times of the evacuation area, it may be considered in the development of evacuation time estimates, and therefore may be included in the MACCS models to more realistically address the effect of shadow evacuation on both the potentially increased evacuation times from within the evacuation zone, and the lower exposures associated with an earlier evacuation of a fraction of the population outside the evacuation zone. It is estimated that 20 percent of the public would evacuate from the shadow areas (Jones et al. 2007, 2011). For each expanded evacuation area, a shadow evacuation region that extends 5 miles beyond the evacuated area is therefore included. Although both states activate sirens for a site area emergency, an early shadow evacuation from within the EPZ was not modeled because the population is very small for this site. This results in the definition of up to three shadow evacuation cohorts, depending upon the extent of expanded evacuation employed. A 10-15 mile shadow evacuation zone is always assumed to be associated with evacuation of the EPZ based off the time of a general emergency. However, in the current model, only a single expanded shadow evacuation model is exercised for any given scenario. Therefore, either a 15-20 mile or a 20-25 mile shadow evacuation zone is modeled for expanded evacuations. A 15-20 mile shadow evacuation is associated with a 10-15 mile expanded evacuation, and a 20-25 mile shadow evacuation zone is associated with a 10-20 mile evacuation.

Non-evacuees

Experience has shown that a small fraction of the public may refuse to evacuate when an evacuation order has been given. This has been recognized since the time of WASH-1400, where it is stated in Section 11.4 that "Civil Defense personnel have observed a minority of approximately 5 percent who stay behind and never evacuate, but the concept of such a nonparticipating minority is not resolvable from the analyses performed" (NRC 1975). In NUREG-1150 (NRC 1990), this was changed to 0.5 percent, with the following rationale provided in Section D.28 of that report:

> "The plants that were studied in NUREG-1150 have detailed and well-maintained emergency plans, which also have provisions for evacuating from special facilities within the EPZ. Because an evacuation is preplanned, it is expected to be nearly complete. The preplanned evacuation should be distinguished from unplanned and impromptu evacuations prompted by transportation accidents involving toxic chemicals, accidents at chemical plants, or natural disasters. The specific value used (0.5 percent) was derived from an actual use of a nuclear emergency plan (for a nearby chemical accident)."

This concept of a very small non-evacuating fraction is consistent with more recent research (Dotson and Jones 2005; Mitchell et al. 2007). A 0.5 percent value was used for this cohort in SOARCA (Bixler et al. 2014). This value appeared reasonable based on discussions with response agencies. This is also supported through research that included a survey of evacuees that identified 98.4 percent of the public evacuated in response to the Graniteville chemical spill (Mitchell et al. 2005, 2007). Thus, 1.6 percent of the public did not evacuate. Considering that the EPZ has a siren system and tone alert radios to alert the public, and the EPZ population receives emergency-response information at least annually and are largely aware of what is expected in a response (NUREG/CR-6953, Vol. 2), the response from within an EPZ should be expected to be more efficient than the ad hoc evacuation for Graniteville. Lastly, the state emergency plan identifies door-to-door contact with residents, if necessary, to assure that all residents in the affected area are alerted to the emergency. Therefore, 0.5 percent still appears to be an appropriate value to represent the non-evacuating public within the area subject to official evacuation orders. In addition, individuals beyond the evacuation zone who are not under evacuation orders are not expected to evacuate. Within areas where shadow evacuations are expected, this is the 80 percent of the population who do not voluntarily evacuate, and beyond the shadow evacuation zone, this represents all (100 percent) of the population.

A non-evacuating cohort is established to represent this group. Shielding parameters are applied to this cohort as though they are performing normal activities. Although this population may shelter, the use of the normal activity shielding factors offers a degree of conservatism in the analysis by taking less credit for sheltering than might be the case. However, this cohort is subject to dose-dependent relocation in the early phase, as discussed in Section 3.4.2.4. The non-evacuating cohorts in the area subject to evacuation orders are combined with the non-evacuees in and beyond the shadow evacuation zone to define the non-evacuating cohort.

Industrial Employees

As previously discussed, the industrial work force of 11,000 was allocated to grid elements based on the location of building clusters and data on the distribution of employee population by specific areas within the site. Because it was assumed that industrial employees live in the vicinity, a corresponding number of residents was removed from grid elements in the areas surrounding the industrial facility. This ensures the population representing the industrial facility work force is not double counted in the analysis. Because MACCS currently estimates the long-term population distribution based on the sum of the individual early-phase cohorts, this cohort is treated as residential for purposes of estimating long-term effects, such as long-term exposure and economic costs. However, there is conversely no ability within the current version of MACCS to attribute economic losses to areas where there is no resident population, and therefore the economic impact of cleanup or interdiction of the facilities at the industrial complex would not be counted if no population was assigned to its area. On balance, it is considered that allocating the employee population to the industrial complex area for long-term effects is a reasonable approach that does not clearly bias long-term consequences as either an overestimate or an underestimate.

Schools

Based on 2013 data from GreatSchools.org, approximately 6000 students attend schools within a 20-mile radius of the site, primarily in the area of the county seat. With the exception of one small private school located near the EPZ boundary, there are no schools or special facility populations located within the EPZ. Schools are primarily located in the county seat, and students are bussed from throughout the area. The school population may therefore be modeled separately for the expanded evacuations. The small private school located within the EPZ has a student population of about 50 and is modeled with the general public response.

Summary of Population from Site File

The final distribution of population, including both the general public (including schools) and the industrial cohorts, is shown in Table 3.4-2.

Table 3.4-2: Summary of population within 100 miles

Distance (mi)	Cumulative Public	Cumulative Industrial	Cumulative Total
0.25	-	-	-
0.5	-	-	-
0.75	-	-	-
1	-	-	-
1.75	25	-	25
2	29	-	29
3	67	-	67
4	292	-	292
5	592	-	592

Table 3.4-2: Summary of population within 100 miles (continued)

Distance (mi)	Cumulative Public	Cumulative Industrial	Cumulative Total
6	1,012	-	1,012
7	1,386	-	1,386
7.5	1,825	-	1,825
8	2,050	-	2,050
9	2,534	-	2,534
10	3,226	2,000	5,226
11	4,235	3,000	7,235
12	5,885	5,000	10,885
12.5	7,051	7,000	14,051
13	8,529	8,000	16,529
14	11,949	11,000	22,949
15	15,902	11,000	26,902
17.5	27,335	11,000	38,335
20	42,961	11,000	53,961
22.5	63,990	11,000	74,990
25	133,099	11,000	144,099
30	355,950	11,000	366,950
40	596,095	11,000	607,095
50	746,243	11,000	757,243
70	1,298,918	11,000	1,309,918
100	3,350,283	11,000	3,361,283

It can be seen from this table that the population within 1 mile of the site boundary (i.e., 0-1.75 miles) is very low. It can also be seen that the fraction of the population within 20 miles, which is the maximum evacuation zone distance used in this analysis, is relatively low in comparison to the population within 50 or 100 miles.

Geographic Allocation

The final set of cohorts is shown in Table 3.4-3.

Table 3.4-3: Summary of cohorts

Cohort Number	Short Name	Description
1	1GP1	0–10 mile general public, first 30%
2	1GP2	0–10 mile general public, second 30%
3	1GP3	0–10 mile general public, third 30%
4	1GPT	0–10 mile general public, final 10% (tail)
5	IND	Industrial facility workers
6	1GPS	10-15 mile general public shadow evacuees, 20%
7	2GP1	10-15 mile general public, first 30%

Table 3.4-3: Summary of cohorts (continued)

Cohort Number	Short Name	Description
8	2GP2	10-15 mile general public, second 30%
9	2GP3	10-15 mile general public, third 30%
10	2GPT	10-15 mile general public, final 10% (tail)
11	SCH	10-15 mile schools
12	2GPS	15-20 mile general public shadow evacuees, 20%
13	3GP1	15-20 mile general public, first 30%
14	3GP2	15-20 mile general public, second 30%
15	3GP3	15-20 mile general public, third 30%
16	3GPT	15-20 mile general public, final 10% (tail)
17	3GPS	20-25 mile general public shadow evacuees, 20%
18	NE	Non-evacuees

These cohorts were defined to accommodate up to a 20-mile evacuation, up to two shadow evacuation zones, and a schools cohort within the 10-15 mile region. To allocate these populations to the correct grid elements in the correct proportions, population distribution matrices were developed to allocate the population of a grid element to the 18 cohorts identified above on a geographically explicit basis. This involves subdividing the grid into geographic subregions and then identifying the fraction of the population within that subregion belonging to each of the 18 cohorts identified above. The geographic subregions were defined as shown in Table 3.4-4.

Table 3.4-4: Location of populations

Population Region	Label	Grid elements
0–10 mile public	1	Rings 1-7, all sectors Rings 8-15, Sectors 1 and 9-64
10-15 mile public	2	Rings 16-20, Sectors 1 and 9-64 Ring 21, all sectors
15-20 mile public	3	Rings 22-23, all sectors
20-25 mile public	4	Rings 24-25, all sectors
>25 mile public	5	Rings 25-35, all sectors
Industrial facility employees	6	Rings 8-20, Sectors 2-8

Evacuation Models

The L3PRA evacuation models comprise options for a 10-mile evacuation zone, a 15-mile evacuation zone, and a 20-mile evacuation zone. Depending upon the time between the declaration of a General Emergency and the onset of a major release, each of these may or may not include a separate cohort to represent the schools population of approximately 6000 in

the 10-15 mile ring that includes the county seat. This results in a total of six potential evacuation models, as shown in Table 3.4-5. A total of six population distribution matrices were therefore defined, corresponding to a 10-mile, 15-mile, or-20 mile evacuation, each of which either did or did not have a schools cohort defined. The population distribution matrices were developed by assuming the following:

- All of the population placed within Rings 8-20, Sectors 2-8 (population 6) was assigned to the industrial cohort.
- The schools cohort, if present, is assumed to comprise 6,000 persons within 10-15 miles. The total population within 10-15 miles is 19,176, of which 6,500 are the industrial employees located within 10-15 miles of the site. The non-industrial population within 10-15 miles of the site is therefore 12,676 persons. Therefore, the fraction of the population within 10-15 miles assigned to the schools cohort (if present) was 0.47 (6,000/12,676). If not present, the schools cohort was simply assigned a fraction of zero.
- The shadow cohort (if present) fraction was assigned, consisting of 20 percent of the remaining population.
- The non-evacuating fraction was assigned, consisting of 0.5 percent of the population in the evacuation zone, 80 percent of the population within a shadow evacuation zone, and 100 percent of the population beyond the shadow evacuation zone.
- The remaining population was divided into three cohorts of 30 percent of the remaining population each, and a tail cohort comprising 10 percent of the remaining population.

The resulting population distribution matrices are provided in Table A.2.

Because the evacuation delay and speed parameters for an individual cohort do not vary by the overall evacuation model, the selection of an evacuation model for a given region can be defined simply by assignment of the population in a grid element to the appropriate cohort using the SUMPOP option. The actual SUMPOP site files can be generated using either the capabilities defined within WinMACCS, or can be developed externally and the site file specified for use by WinMACCS. This allowed the selection of the evacuation model to be performed efficiently simply by defining the appropriate SUMPOP site file within the WinMACCS project file, rather than using WinMACCS to generate a SUMPOP site file for each source term. A Python 2.7 script was therefore developed for use in the Level 3 analyses. This script read in (1) the base-case site file, (2) a file defining the population region assignments, and (3) each of the six possible population distribution matrices provided in Table A.2. This allowed the development of a separate SUMPOP file for each potential evacuation model, as listed in Table 3.4-5. This approach facilitates the selection of EP models by allowing the MACCS project file to contain all the information for any given cohort, and applying that cohort simply by selecting the appropriate site file (i.e., a site file that has a non-zero population for that cohort).

Table 3.4-5: Evacuation models and associated site file names

Evacuation region	No school cohort included	School cohort included
0–10 mile evacuation	EP1: [*SITE*]_2017_10_13_EP1.inp	EP1S: (not used)
0–10 mile evacuation followed by 10-15 mile evacuation	EP2: [*SITE*]_2017_10_13_EP2.inp	EP2S: [*SITE*]_2017_10_13_EP2S.inp
0–10 mile evacuation followed by 10-20 mile evacuation	EP3: [*SITE*]_2017_10_13_EP3.inp	EP3S: [*SITE*]_2017_10_13_EP3S.inp

3.4.2.2 *Characterization of Exposure Pathways*

Off-Centerline Correction Factors

The primary environmental concentrations calculated in the ATMOS module include the integrated plume centerline ground-level atmospheric concentration (Bq-s/m^3) and integrated deposition (Bq/m^2) below the plume centerline. However, transverse dispersion results in concentrations away from the centerline of the plume that are less than those of the plume centerline. To compute doses to individuals who are not under the plume centerline, MACCS computes an off-centerline correction factor as described in (Jow et al. 1990), Section 3.1.1 (for early-phase exposure pathways) and in Section 3.2.1 (for the intermediate- and late-phase exposure pathways). The correction factor for the early-phase exposure pathways is computed by approximating the Gaussian distribution in the crosswind direction as a set of steps with the number of steps controlled by the MACCS variable NUMFIN. The factor is defined as the ratio of the height of the crosswind histogram at a given distance from the plume centerline to the height of the Gaussian peak. Because there is no significant computational penalty associated with using the highest resolution possible, this factor is defined with a value of NUMFIN equal to 7. A single crosswind correction factor for intermediate- and late-phase exposure pathways is used and is defined as the average of the early-phase crosswind corrections factors.

Shielding and Protection Factors

Shielding and exposure factors (also termed dose-reduction factors) are specified for each dose pathway (cloudshine, groundshine, inhalation, and skin protection) in MACCS and they directly affect the doses received by individuals. These factors are based on occupancy-weighted estimates of the ratio of the unprotected (i.e., standing outdoors on a flat surface and completely unprotected from exposure to airborne or deposited radioactivity) to the protected dose. This ratio is sometimes termed the location factor. The location factors are multipliers on the dose that a person would receive if there were no shielding or protection. Thus, a location factor of one represents the limiting case of a person receiving the full dose (i.e., standing outdoors on a flat surface and completely unprotected from exposure). A location factor of zero represents the limiting case of complete protection from exposure. Because individuals may be in any of a number of locations, each of which may have a different location factor (i.e., in the upper floors

of a wood-framed house, in a residential basement, in a vehicle, outdoors, etc.), the occupancy patterns must also be considered. The typical approach to the derivation of shielding and protection factors is to estimate a weighted average factor, taking into account the fraction of the population that may be in each location, depending upon the activity pattern (normal activity, active sheltering, or evacuation). For an individual outdoors, some measure of protection is also afforded by factors such as shielding from nearby structures and ground roughness. Shielding and exposure factors are derived for normal activity, active sheltering, and evacuation for each MACCS dose pathway (i.e., inhalation, deposition onto skin, cloudshine, and groundshine), resulting in a set of 12 factors. These may be defined for each emergency-phase cohort; for example, shielding factors for special populations residing in large structures, such as hospitals, may be defined to account for the additional shielding offered by such structures. The basic methodology was developed in WASH-1400 (see Section 11.3 of [NRC 1975] for more information), and was updated in Section 3.2 of (Sprung et al. 1990) who derived site-specific values from information on the geographic distribution of multiunit structures and state-specific information on the fraction of newly constructed residences with basements. The results of that analysis suggested that the normal activity shielding values did not vary greatly among sites, but that the sheltering values could vary on a site-specific basis, largely because of the significant differences in the availability of basements for sheltering across different areas of the country.

In the 1990s, shielding and exposure factors were the subject of an expert elicitation (Goossens et al. 1997). In the elicitation, both the location factor (for groundshine) and occupancy patterns of the general public in seven types of locations were considered:

- inside a low shielding building (e.g., a wooden framed house)
- inside a medium shielding building (e.g., a typical brick family house)
- inside a high shielding building (e.g., a tall multistory building)
- inside the basement of a single-family house
- in the basement of a multistory building
- in a typical car on a suburban street
- in a typical bus on a suburban street

The elicitation did not specify the locations within building, characteristics of the buildings (e.g., mass per unit area of walls or numbers and locations of windows), deposition mechanisms, or relative deposition distributions for the various surfaces (including internal surfaces). These values were postprocessed by (Gregory et al. 2000) to yield a recommended parameter distribution for the groundshine factor. The geographic region is not specified, but it appears that this is consistent with a generic site based on discussions of reference to the use of U.S. average occupancy fractions. As previously noted, the most likely source of geographic variability would be in the sheltering groundshine/cloudshine values, largely due to the availability of basements.

For both the derivation of cloudshine and groundshine factors, vinyl-sided housing is a good surrogate for many other light construction housing types, such as wood siding, aluminum siding, stucco, etc.; brick siding is unique in that it offers more shielding than other housing types. The values used in MACCS represent an average across a range of occupancy patterns

and structure types. For individual cohorts, other values may be appropriate. For example, housing constructed of mortar filled concrete block provides substantially more shielding than brick siding because the material is about twice as thick. Also, commercial (e.g., office buildings and hospitals) and government buildings are often constructed from heavier materials, such as stone or thick concrete. Some cohorts may live or shelter in such buildings and those cohorts should have substantially lower factors.

The inhalation and skin deposition factors are both based on the ratio of the time-integrated airborne concentration in the protected location to the time-integrated ground-level outdoor air concentration. These may be derived using a simple single or multiple compartment model. Considerations for determining appropriate values for inhalation and skin factors include:

- Air tightness of building or structure. Modern homes are often built to high levels of air tightness.
- Integrity of building or structure. For example, windows may be closed, open, or even broken because of an earthquake. These factors may change over the course of the year; for example, windows are more likely to be open during warm weather and closed during the heating season.
- Air exchange with exterior through HVAC system or from open windows or doors. Because a measure of ventilation is needed for structures due to indoor air quality and moisture control concerns, forced ventilation may be used to ensure the appropriate level of ventilation during normal activity. Such ventilation may be shut off during periods of active sheltering.

Because there is always some air exchange between the indoor and outdoor air, the duration of cloud passage may also be important, with longer times of cloud passage giving rise to more infiltration of outdoor air. The location within the building is not as important as with protection from sources outside the building if the air within the structure is assumed to be well mixed (i.e., the structure is modeled as a single ventilation compartment). Values appropriate for active sheltering should take into account the potential for shutdown of forced ventilation systems, in which case the ventilation of the structure would be due to pressure differentials between the interior and exterior of the structure due to wind.

Older versions of MACCS assumed that the long-term shielding and exposure factors in the intermediate and long-term phases are identical to those for normal activity during the emergency phase. This is still a reasonable assumption that is commonly used. However, there are some reasons why the factors could be different for these phases. One basic difference is in potential equilibration between the exterior and interior of buildings. The usual assumption in estimating these factors for the emergency phase is that the exterior is contaminated but the interior is clean. This may be a reasonable assumption for the short term, but may be less appropriate for the long term. Even for the short term, air exchange between the interior and exterior of a house or other building can cause some level of contamination to the interior. Filtered air exchange between the atmosphere and a control room is generally included when assessing doses to control room workers for design-basis accidents. Similarly, ventilation systems in a home or other building would gradually introduce contaminants into the interior,

which in turn would affect the shielding and exposure factors. After a long time, it is reasonable that the interior and exterior of a building would equilibrate. In other words, the contamination level of the interior of a building would be lower but proportional to the contamination level of the exterior of the building. Also, as discussed previously, the energy spectrum of the deposited material may change over time as short-lived radionuclides decay. By allowing a distinction between short-term and long-term shielding and exposure factors, MACCS can be used to evaluate possible time dependencies of these factors.

For this analysis, it was decided that the values recommended by (Gregory et al. 2000) are reasonable values for groundshine shielding factors (GSHFAC, LGSHFAC), as well as for skin protection (SKPFAC) and inhalation protection factors (PROTIN). These values are considered reasonable for this analysis, as they represent the most recent recommendation and facilitate the performance of uncertainty analyses. These values are considered reasonable for a generic site, and could be rederived using the information in (Goossens et al. 1997), coupled with site-specific information related to occupancy fractions and building types, to yield a site-specific value. It is expected that such an exercise would largely affect the groundshine sheltering values. However, because this could be a resource-intensive exercise, and this analysis is intended to be a state-of-practice analysis, such a site-specific reanalysis was not conducted. As discussed in Section 3.4.4, sensitivity analyses using the distributions provided in Tables 3.4-6 and 3.4-7 would be useful in determining whether such an exercise would be warranted.

The values for the groundshine shielding factor are given in Table 3.4-6, adapted from Table 4.11 of (Gregory et al. 2000). For members of the general public and for a generic site, the values provided in Table 4.11 of (Gregory et al. 2000) are considered reasonable. The median value from this distribution, rounded to two significant figures, was used in this analysis for general public cohorts. The values for normal activity and sheltering may vary by cohort because they are based on the robustness of the buildings or facilities in which the cohort resides or shelters. Special facilities, such as hospitals or schools, consist of robust structures that provide greater shielding than single-family dwellings. For this analysis, the normal activity groundshine shielding values were set to the sheltering value of 0.1 for special facilities (schools and the industrial cohort), consistent with the project-specific recommendation from SNL.

Table 3.4-6: Recommended generic groundshine factor

Quantile	Normal Activity	Sheltering	Evacuation
0.00	5.28E-02	1.53E-02	8.33E-02
0.01	6.83E-02	2.22E-02	1.28E-01
0.05	9.51E-02	3.47E-02	1.82E-01
0.15	1.29E-01	4.74E-02	2.43E-01
0.25	1.54E-01	6.38E-02	2.80E-01
0.50	2.16E-01	1.04E-01	3.96E-01
0.75	3.03E-01	1.68E-01	5.52E-01
0.85	3.46E-01	2.03E-01	6.40E-01

Table 3.4-6: Recommended generic groundshine factor (continued)

Quantile	Normal Activity	Sheltering	Evacuation
0.95	4.17E-01	2.50E-01	7.55E-01
0.99	4.89E-01	2.88E-01	8.70E-01
1.00	5.48E-01	3.31E-01	9.35E-01

Source: adapted from Table 4.11 of (Gregory et al. 2000)

LGSHFAC is the groundshine factor used for the intermediate and long-term phases. Generally, this parameter is chosen to be the same as GSHFAC for normal activity during the emergency phase. Consideration may be given to reducing this value to account for the generally lower energy radiation associated with Cs-137, or increasing it due to potential deposition of contaminated soil on interior surfaces. For this analysis, the normal activity values from Table 3.4-6 were used for LGSHFAC.

PROTIN is the set of inhalation protection factors for normal, evacuation, and sheltering activities. The technical bases for these values were considered in the elicitation documented in (Goossens et al. 1997). For members of the general public and for a generic site, the values provided in Table 4.11 of (Gregory et al. 2000, are considered reasonable. The values for the inhalation protection factor are given in Table 3.4-7, adapted from Table 4.11 of (Gregory et al. 2000). The median value from this distribution, rounded to two significant figures, was used in this analysis for general public cohorts. Special facilities, such as hospitals or schools, may provide greater filtration and protection from outside air than single-family dwellings. For this analysis, the values recommended by SNL for special facilities (schools and the industrial cohort), based on SOARCA (Bixler et al. 2014) were used. These were 0.98 for evacuation, 0.33 for normal activity, and 0.33 for sheltering.

Table 3.4-7: Recommended generic inhalation protection factor

Quantile	Normal Activity	Sheltering	Evacuation
0.00	7.60E-02	1.48E-02	2.30E-01
0.01	1.04E-01	1.62E-02	2.32E-01
0.05	1.52E-01	2.20E-02	2.44E-01
0.15	2.77E-01	7.25E-02	3.50E-01
0.25	3.94E-01	1.24E-01	4.57E-01
0.50	6.92E-01	2.51E-01	7.24E-01
0.75	8.62E-01	6.24E-01	8.77E-01
0.85	9.30E-01	7.73E-01	9.38E-01
0.95	9.99E-01	9.22E-01	9.99E-01
0.99	1.00E+00	9.84E-01	1.00E+00
1.00	1.00E+00	1.00E+00	1.00E+00

Source: adapted from Table 4.11 of (Gregory et al. 2000)

LPROTIN is the inhalation protection factor used in the CHRONC module for the intermediate and long-term phases. It is comparable to PROTIN, which is used for the emergency phase. Although this parameter may be chosen to be the same as PROTIN for normal activity during the emergency phase, for this analysis LPROTIN was conservatively set to a value of 1 to reflect the potential for long-term equilibration between indoor and outdoor atmospheric concentrations.

SKPFAC is the set of skin protection factors for normal, evacuation, and sheltering activities. Considerations for skin protection factor are the same as those for inhalation protection factor, because both are based on the ratio of the interior to exterior time-integrated air concentration. Accordingly, in this analysis, the same values used for PROTIN were used for SKPFAC.

BRRATE is breathing rate and can vary by age, gender, and activity. Inhalation dose is proportional to breathing rate. Although this variable may be specified for the three types of activity, for most analyses, an age, gender, and activity averaged breathing rate is recommended for all three activities and for all cohorts for consistency with the inhalation dose factors. The value of 0.000266 m^3/s recommended by (Sprung et al. 1990) is consistent with a population-averaged breathing rate. This value was also examined in the NRC-CEC expert elicitation on internal dosimetry (Goossens et al. 1998) and was postprocessed by (Gregory et al. 2000) to obtain the distribution shown in Table 3.4-8. The median value from this distribution was used for this analysis. Because the cohorts defined in this analysis could largely be expected to represent a relatively similar age and gender distribution, the use of the generic value provided in Table 3.4-8 is considered reasonable for all cohorts, particularly for cohorts representing the general public. In principle, there could be some age- and gender-dependence in the special facilities cohorts. However, introduction of an age- and gender-dependent breathing rate, without consideration of the age and gender dependence of the inhalation dosimetry, would introduce an inconsistency in the dosimetric modeling, and it was therefore decided to use the same generic values for all cohorts. As discussed in Section 3.4.4, sensitivity analyses using the distributions in Table 3.4-8 could provide information on whether the effort needed to generate specific breathing rates would be warranted.

Table 3.4-8: Recommended breathing rates

Quantile	Breathing Rate (m^3/s)
0%	9.22E-05
5%	1.38E-04
50%	2.19E-04
95%	3.93E-04
100%	5.90E-04

Source: adapted from Table 4.11 of (Gregory et al. 2000)

LBRRATE is the CHRONC parameter for breathing rate and the value of this parameter is used during the intermediate and long-term phases. It is comparable to BRRATE, which is the

breathing rate used during the emergency phase, and is normally chosen to have the same value.

CSFACT is the set of cloudshine factors for normal, evacuation, and sheltering activities. These values were not assessed in the expert elicitation documented in (Goossens, et al. 1997). Accordingly, (Gregory et al. 2000) referenced values from an earlier sensitivity and uncertainty analysis (Helton et al. 1995b) that was based on the analyses in (Sprung et al. 1990). The following recommended values for the general public for a generic site are from Table 4 of (Helton et al. 1995b):

- Evacuation: 0.95 (0.9-1)
- Normal Activity: 0.75 (0.6-0.95)
- Sheltering: 0.6 (0.5-0.7)

The best estimate values from Table 4 of (Helton et al. 1995b) are considered reasonable for this analysis for general public cohorts, as they represent the most recent recommendation and facilitate the performance of uncertainty analyses. Special facilities, such as hospitals or schools, consist of robust structures that provide greater shielding than single-family dwellings. For this analysis, the values recommended by SNL for normal activity and sheltering for special facilities (schools and the industrial cohort), based on SOARCA (Bixler et al. 2014), were used. These were 0.31 for normal activity and 0.31 for sheltering.

Weathering and Resuspension Factors

Weathering and resuspension factors are based on the values used in NUREG-1150. The technical basis for these values is provided in Section 2.7 of (Sprung et al. 1990). Weathering is modeled using a first-order removal model. For groundshine, the effect of weathering on reducing external doses from groundshine is based on the model developed by (Gale et al. 1964). Groundshine weathering is only considered in the intermediate and long-term phases. The form is:

$$GW(t) = \sum_i GWCOEF_i \cdot e^{-\frac{\ln(2)}{TGWHLF_i}t}$$

where GW(t) represents groundshine weathering factor at time t given the weathering coefficients, GWCOEF(i), and the weathering half-lives, TGWHLF(i). That study examined the time-dependent external exposure from a deposition of Cs-137 on several experimental plots with different soil types, and found that the results could be fit with a two-compartment model, with approximately 63 percent of the dose rate decaying with a half-life on the order of about 7 months, and approximately 37 percent of the dose rate decaying with a much longer half-life (on the order of 92 years). The values recommended in (Sprung et al. 1990) included consideration of more recent data, including studies on impermeable surfaces in Denmark (Warming 1982 1984), which demonstrated that 40-60 percent of the contamination deposited on concrete weathered with a half-life of about 3 months (depending on whether the concrete was fresh or aged), and 0-60 percent of the contamination deposited on asphalt weathered with a half-life of

60 days. In both cases, aged surfaces exhibited the least weathering. Karlberg (1987) and (Jacob et al. 1987) examined the behavior of post-Chernobyl deposits in Sweden and Bavaria, respectively. Based on that data, and on reviews carried out in NUREG/CR-4185 (Runkle and Ostmeyer 1985), (Sprung et al. 1990) recommended that a two-compartment model, with half decaying with a weathering half-life of 6 months and half decaying with a weathering half-life of 90 years, be used for modeling the drop in groundshine associated with the initial deposition.

Resuspension is modeled based on the data in the review article by (Sehmel 1984), as summarized in (Sprung et al. 1990) Section 2.9. MACCS uses a single-compartment model for emergency-phase resuspension weathering, and a three-compartment model for resuspension weathering in the intermediate and long-term phases modeled in CHRONC. RESCON represents the initial value for the emergency-phase resuspension factor, and RWCOEF represents the leading coefficients in the chronic resuspension factor. The resuspension factor model is thus similar to the groundshine weathering model above, with one weathering compartment (i=1) for the emergency phase and three weathering compartments (i=3) in the intermediate and long-term phases.

$$RW(t) = \sum_i RWCOEF \cdot e^{-\frac{\ln(2)}{TRWHLF_i}t}.$$

Where RW(t) represents the resuspension weathering factor at time *t*, given the weathering coefficients, RWCOEF(i), and the weathering half-lives, TRWHLF(i). The recommended values for the resuspension weathering factors are given in Table 3.4-9.

Table 3.4-9: Resuspension factors and half-lives

	EARLY	CHRONC TERM1	CHRONC TERM2	CHRONC TERM3
RESCON/ RWCOEF (m^{-1})	0.0001	0.00001	0.0000001	0.000000001
RESHAF/ TRWHLF (s)	182,000 (50 hrs)	16,000,000 (6 mos)	160,000,000 (5 yrs)	1,600,000,000 (50 yrs)

Food Ingestion Pathways

Ingestion modeling is included in this analysis because estimates of collective dose and economic impacts can both be affected by ingestion pathways (either contributing to collective doses if agricultural products are not interdicted, or contributing to costs if agricultural products are interdicted). Modeling of the collective doses from ingestion of contaminated food in this analysis is based on the COMIDA food-chain model (Abbott and Rood 1993, 1994). The COMIDA code estimates nuclide concentrations in agricultural food products following an acute fallout event. COMIDA is a dynamic food-chain model that models the transfer of radionuclides into the edible portion of plants as a function of plant growth. In addition, COMIDA accounts for linear decay chains up to four nuclides in length, and can consider ingrowth after deposition. COMIDA models transport through the human food chain and calculates the respective nuclide concentration in nine foodstuffs (grains, leafy vegetables, roots, fruits, legumes, milk, beef, poultry, and “other animal”), based on an initial unit deposition. All COMIDA calculations are

performed for one user-specified accident day of the year, or "fallout" date, and foodstuff concentration data can be calculated for up to 50 years following the accident, reported as both 1-year or cumulative (0 to N yrs) values. COMIDA2, developed at SNL, serves as an interface program between COMIDA and MACCS, and is described in detail in Section 2 of (Chanin and Young 1998b). COMIDA2 adds three functional capabilities to COMIDA: (1) the ability to consider multiple accident dates in the year (up to nine in a single run); (2) calculation of projected and accumulated doses (per unit deposition), considering food consumption rates, agricultural productivity, and processing losses; and (3) a free-format user input file processed according to the conventions of MACCS, which specifies the additional input data required by the newly added code features. COMIDA2 exercises COMIDA a number of times to generate the information needed for the MACCS run. It automatically loops on multiple fallout dates, translates the COMIDA-calculated foodstuff concentrations into units of dose broken down by crop category, and writes a binary file of dose-to-source ratios for use by MACCS. Providing data for multiple accident dates allows MACCS to consider the variability in ingestion dose due to seasonality effects. The COMIDA model is invoked by setting the MACCS variable FDPATH to NEW (thereby using the COMIDA files and bypassing the original MACCS food model) and assigning the name of the COMIDA file.

The treatment of agricultural countermeasures associated with the COMIDA-based food model in the MACCS code is described in Section 7.10.1 of (Chanin and Young 1998a). Agricultural countermeasures are modeled in the COMIDA-based food model by specifying three dose limit parameters. DOSEMILK and DOSEOTHR define the maximum allowable food ingestion dose to an individual from milk production and other food crops, respectively, during the year of the accident. These parameters are not used beyond the first year. For each subsequent year, MACCS compares the estimates of individual doses from consumption of milk and other agricultural food products to the values of DOSELONG. Depending on the result, for a given year, the farmland is either interdicted, or allowed to be in production.

Although the SOARCA project did not include modeling of the food pathway, a new sample COMIDA file was developed to be consistent with the dosimetry files developed for the SOARCA project. The L3PRA project uses the COMIDA file developed to be consistent with the SOARCA project, which was derived using the updated dose coefficient files discussed in Section 3.5 and is named comida2_FGR13GyEquivDCF.bin The basis for the COMIDA parameter values used to develop COMIDA files distributed with MACCS is described in Section 2.6 of (Chanin and Young 1998b). Much of the input for this sample problem was obtained from NUREG/CR-5512 (Kennedy and Strenge 1992) and a description of the PATHWAY code (Whicker and Kirchner 1987). The values are therefore generic non-site-specific values; an independent review of the COMIDA input parameters was not performed. In particular, values for the agricultural productivity used for the calculation of societal doses are based on a generic assumption that 1 km^2 of farmland would provide a U.S. average market basket of agricultural products for 100 persons. As discussed on page 2-10 of (Chanin and Young 1998b), an agricultural census of the region could be undertaken, wherein the agricultural productivity of each foodstuff is simply the amount produced in the region divided by the area of the region. Because agricultural production is subject to large variations due to weather and the economic cycle, several years of data would probably be required. Likewise, site-specific values for milk

cow pasture consumption and seasonal dates for tillage, growing and grazing season, and harvest times could vary from those used to develop the sample problem. The use of generic data for the COMIDA file is a potential source of uncertainty in the analyses that could affect the MACCS outputs related to the food ingestion pathway.

The values used to represent agricultural countermeasures in this analysis are based on recent work to update MACCS cost parameters related to protective measures and are as recommended in (Jones, Bixler and Kimura 2015). The recommended values, which are given in Table 3.4-10, are based on scaling of values derived to ensure meeting guidelines for infants, which tend to be the most restrictive set of guidelines. Since the dose coefficients used in the project are based on adult dose coefficients, values for DOSEMILK, DOSEOTHR, and DOSELONG were derived to use with adult dose coefficients. Dose limits were originally derived to represent Codex Alimentarius limits (FAO 2009), and then scaled to represent FDA PAGs. To derive estimates for these parameters, two pairs of MACCS problems were produced. One pair was concerned with an inventory based on a long-term station blackout; the other pair involved an inventory based on aged PWR spent fuel. For each inventory type, two problems were created, one with ingestion DCFs and a COMIDA2 file appropriate for an infant, and one using dose coefficients and COMIDA2 files appropriate for an adult. Each of the COMIDA2 files included each isotope listed in the Codex Alimentarius, except tritium. The adult problems used the standard dietary intake values for an adult from the NRC sample problem POINT ESTIMATES LNT, which is distributed with WinMACCS. The adult dietary values used in POINT ESTIMATES LNT are somewhat different than those listed in the FDA PAG document. Based on these results, values of DOSEMILK = 0.000075 Sv, DOSEOTHR = 0.00028 Sv, and DOSELONG = 0.00028 Sv effective dose were used in this project as a starting point for use with adult dose coefficients in implementing the Codex Alimentarius recommendations. Scaling factors were then derived to convert agricultural countermeasure parameters derived for Codex limits to simulate FDA limits. The rationale for these scaling factors is the following: (1) the ratio of the limiting dose allowed by the FDA (0.5 rem per year) is a factor of 5 times larger than the limiting dose allowed in the Codex (0.1 rem per year) and (2) the dose limit allowed to an individual tissue by the FDA is 10 times greater than the effective dose limit (5 rem for an individual tissue compared with 0.5 rem effective). The values for DOSEMILK, DOSEOTHR, and DOSELONG were therefore scaled (multiplied) by a factor of 5 for effective dose, then scaled again (multiplied) by a factor of 10 for thyroid dose to develop the values used in the L3PRA project. The recommended values are lower than the adult FDA PAG limits because they account for the higher dose that an infant would receive compared with an adult. The recommended values for these variables are provided in Table 3.4-10.

Table 3.4-10: Food interdiction parameters

Parameter	Description	Value
DOSEMILK	Max milk dose first year	0.0375 rem effective 0.375 rem thyroid
DOSEOTHER	Max nonmilk dose first year	0.14 rem effective 1.4 rem thyroid
DOSELONG	Max nonmilk dose subsequent years	0.14 rem effective 1.4 rem thyroid

The values for the first year countermeasure parameters are substantially lower than the earlier values recommended in Sample Problem A of 2.5 rem effective dose and 7.5 rem to the thyroid and would result (other factors being equal) in a wider extent of agricultural interdiction than would have been generated by the earlier values. The values for out years are only slightly smaller than the earlier values recommended in Sample Problem A of 0.5 rem effective and 1.5 rem to the thyroid. Staff considers these values to be reasonable, given that widespread precautionary interdiction in the year of the accident is expected based on discussions with offsite response organizations.

The milk and crop disposal cost calculations are described in (Chanin and Young 1998a). If the disposal of the first year's milk production is triggered because the dose criterion DOSEMILK is exceeded, milk disposal costs are assessed as 0.25 of annual milk sales. The rationale for the reduction in milk disposal costs by the application of the 0.25 adjustment factor was based on the assumption that cows would be taken off pasture and fed uncontaminated feed, allowing dairy production to resume after one-quarter of a year. In order to maintain consistency with the MACCS food-chain model, the application of the fixed 0.25 adjustment factor on milk disposal costs has also been implemented for the COMIDA2 food-chain model (Chanin and Young 1998b).

Water Ingestion Pathways

The collective dose associated with water ingestion considers doses arising from drinking water contaminated by direct deposition onto freshwater bodies and by washoff from contaminated land into freshwater bodies. The model used in MACCS for estimating collective drinking water doses is described in Section 3.2.5 of (Jow et al. 1990), based on a model developed by (Helton et al. 1985). It can be shown that the MACCS model for collective dose (either equivalent or effective) from a given radionuclide reduces to the form:

$$D = C \cdot A \cdot DCF \cdot TF_{SURF} \cdot TF_{HUM}$$

Where
C: Initial surface concentration of radionuclide (Bq/m^2) in a spatial element
A: Total area of the spatial element (m^2)
DCF: Ingestion dose coefficient (Sv/Bq ingested) from the MACCS dose coefficient file
TF_{SURF}: Fraction of material deposited in the spatial element that eventually enters the source of drinking water (i.e., surface water bodies)

TF_{HUM}: Fraction of material in the source of drinking water (e.g., surface water bodies) that is eventually consumed by humans

The fraction of material deposited in the spatial element that eventually enters the source of drinking water (i.e., surface water bodies) is computed in MACCS as the sum of three elements: the amount deposited directly on the surface water body, the amount deposited initially on land that is assumed to instantaneously wash off into the surface waters, and the amount deposited initially on land that washes off into surface waters as a result of longer term processes. Assuming that the rate of long-term removal can be approximated as a first-order process characterized by a rate constant λ_{WASH}, the transfer function for surface water (TF_{SURF}) in MACCS can be shown to reduce to the form:

$$TF_{SURF} = \left[TF_{DIRECT} + TF_{INDIRECT,\,SHORT} + TF_{INDIRECT,\,LONG}\right]$$
$$= \left[(1\text{-}f_{LAND}) + (f_{LAND} \cdot f_{SHORT}) + \left(f_{LAND} \cdot (1\text{-}f_{SHORT}) \cdot \frac{\lambda_{WASH}}{\lambda_{RAD} + \lambda_{WASH}}\right)\right]$$

Where
f_{LAND}: fraction of the spatial element represented by land, as read from the site file (the remainder is assumed to be surface water)
f_{SHORT}: fraction of material deposited on land that is assumed to be transported to surface water instantaneously (i.e., without any decay), represented by the MACCS variable WSHFRI
λ_{WASH}: rate constant at which deposited material remaining on the land surface is washed into surface water bodies, represented by the MACCS variable WSHRTA
λ_{RAD}: radiological decay constant for the radionuclide

The fraction of material in the source of drinking water (e.g., surface water bodies) that is eventually consumed by humans (TF_{HUM}) is represented by the MACCS variable WINGF, which is read from the MACCS site file. The value for this variable was evaluated in (Sprung et al. 1990) based on data from (Helton et al. 1985) for both large river systems and large lakes. For large river systems, the expression for WINGF can be determined to be (Equation 2.16 from [Sprung et al. 1990])

$$TF_{HUM} = f_{treatment} \cdot \frac{N \cdot DR}{Q}$$

Where
$f_{treatment}$: water treatment factor, i.e., the ratio of the radionuclide concentration before and after treatment (dimensionless)
N: population obtaining drinking water from the river system (persons)
DR: Individual annual drinking water consumption (L/yr)
Q: Annual river discharge (L/yr)

A similar approach can be used to develop values for lakes or impoundments, and can be given (Equation 2.21 in [Sprung et al. 1990]) by

$$TF_{HUM} = f_{treatment} \cdot \frac{N \cdot DR}{\lambda_{REMOVAL} \cdot V}$$

Where

$\lambda_{REMOVAL}$: rate constant for removal by radioactive decay, sedimentation, outflow, etc (1/yr)

V: volume of the lake or impoundment (L)

For large river systems, drinking water represents a small fraction of the surface water available. Likewise, the large volume of lakes in the U.S., coupled with a relatively rapid removal rate, implies that only a small fraction of the material washed into a large lake or impoundment would end up being consumed along with drinking water. The analyses in (Sprung et al. 1990) provide estimates for the value of WINGF, which they characterized as ballpark estimates suitable for a preliminary assessment of the drinking water pathway.

The water ingestion pathway values recommended for NUREG-1150 in (Sprung et al. 1990), based on the analyses in (Helton et al. 1985), were selected for use in this analysis, and are given in Table 3.4-11. The values of WINGF are consistent with those for systems where large rivers are the source of drinking water. The uncertainty in these values was evaluated in (Sprung et al. 1990) to span approximately one order of magnitude.

Table 3.4-11: Watershed transport factor parameters

NAMWPI	Instantaneous Washoff Fraction (WSHFRI)	Long-term washoff rate constant (WSHRTA)	Consumption Fraction (WINGF*)
Sr89	0.01	0.004	5e-6
Sr90	0.01	0.004	5e-6
Cs134	0.005	0.001	5e-6
Cs137	0.005	0.001	5e-6

**In this analysis, the value for WINGF is read from the site file prepared by SecPop.*

Phase Durations, Exposure Periods, and Commitment Periods

The emergency-phase duration is represented by the ENDEMP parameter and represents the time from the accident initiation until the end of the early response. The duration of this phase can vary depending on the accident (EPA 2013). Because some of the releases modeled in this analysis began late and were somewhat prolonged, a value of 10 days was selected for ENDEMP for all cases to allow sufficient time for releases to end and for the plume to travel through the problem area.

The duration of the intermediate phase is defined by the DUR_INTPHAS parameter, for which MACCS allows a maximum of 365 days. The EPA defines an intermediate phase as a time during which releases are brought under control but have not necessarily stopped (EPA 2013). EPA explains that the intermediate phase may overlap with the early phase and late phase. The MACCS intermediate phase definition differs from EPA in that the MACCS phases are discrete and do not overlap. Releases are complete by the end of the early phase in the MACCS

framework. The duration of the intermediate and recovery phases are estimated using a process adapted from project-specific recommendations provided by SNL. The process involves estimating the size of different affected populations using a preliminary analysis which entails use of only a single non-evacuating cohort to estimate the potential extent of different types of protective actions. Rather than estimating phase durations based on projected affected areas, as recommended by SNL staff, the durations are based on the size of the affected population. This assumption was made because the area and size are approximately related, and because information from Fukushima (IAEA 2015) suggests that most recovery actions would be focused on areas adjacent to residences, farmland, and public spaces. The duration of the intermediate phase (DUR_INTPHAS) was established as follows:

- No offsite contamination – no intermediate phase necessary
- Limited offsite contamination, where small areas (e.g., acres) of farmland or uninhabited land are contaminated – 3 months. This was defined in terms of magnitude of affected population, where the cutoff population was taken as 100 persons.
- Moderate offsite contamination, where small areas (e.g., hundreds of acres) of farmland or low density populated areas are contaminated – 6 months. This was defined in terms of magnitude of affected population, where the cutoff population was taken as 1000 persons.
- Extensive offsite contamination (e.g., square miles) of populated land requiring interactions with many different stakeholders – 12 months. This was defined in terms of magnitude of affected population, where the cutoff population was taken as greater than 1000 persons.

Each of these four potential assignment levels were assigned to individual release categories based on the results of preliminary analyses, and are provided in Table 3.4-12. The preliminary analyses suggested that while small releases (i.e., scrubbed releases or no failure of the containment to the atmosphere) may result in only limited numbers of affected people, most unscrubbed releases would lead to more extensive offsite protective actions in the intermediate phase and necessitate a relatively long intermediate phase.

Table 3.4-12: Sequence-specific intermediate phase durations

Case	Release Category	DUR_INTPHAS (months)
1A2	ICF-BURN	12
1A2 (truncated at 28 hr)	ICF-BURN-SC	3
1B	LCF	12
2A	ECF	12
2R1	NOCF	3
2R2	LCF-SC	3
3A2	ISGTR	12
5	V	3
5B	V-F-SC	12
5D	V-F	12
6	BMT	3
7	CIF	12

Table 3.4-12: Sequence-specific intermediate phase durations (continued)

Case	Release Category	DUR_INTPHAS (months)
7A	CIF-SC	12
8	SGTR-C	12
8B	SGTR-O	12
8BR1	SGTR-O-SC	12

Doses reported in the MACCS EARLY phase results represent external exposures accumulated over the early period and committed doses from intakes during the early period. In the early phase, the exposure period is therefore defined by the duration of the emergency phase defined by the variable ENDEMP. Since groundshine and cloudshine are external pathways, doses received are concurrent with the exposure. The exposure period for internal pathways, inhalation and ingestion, is the period of time when the inhalation or ingestion occurs; however, doses from inhalation and ingestion continue to be received following the exposure. The period of time over which doses are received from an internal pathway is accounted for in the construction of dose coefficients by integrating the doses over a finite period, called a dose commitment period. For purposes of computing latent health effects, the dose commitment period is taken to be 50 years when calculating internal pathway dose coefficients for adults. The implicit assumption is that the average adult lives for an additional 50 years following the exposure. For purposes of computing deterministic health effects from acute exposures following inhalation of material during cloud passage, the exposures are integrated over 7 days, and the effect of dose fractionation is considered, as discussed in Section 3.5. Exposures from inhalation during each year of the long-term phase contribute to doses received over the subsequent 50-year commitment period.

Doses received in the first year thus correspond to:

- most of the dose from internal exposure during the emergency phase
- most of the dose from internal exposure during the first year of the long-term phase
- all of the dose from external exposure during the emergency phase
- all of the dose from external exposure during the first year of the long-term phase

Doses received in the second and subsequent years correspond to:

- all of the dose from external exposure during that year
- a fraction of the dose from internal exposure during all previous years
- dose from internal exposure during that year

The exposure pathways used for calculating the total dose commitment during the intermediate phase are similar to those in the early phase, except that doses from cloudshine and direct inhalation are not computed because the cloud has already passed. The pathways include groundshine and resuspension inhalation. The exposure duration in the intermediate phase is the duration of the intermediate phase (DUR_INTPHAS). The long-term phase exposure period

begins in MACCS once reoccupancy is allowed (which may be immediately after the accident or may not occur until several years after the accident, depending upon the duration of the intermediate phase, decontamination period, and any additional interdiction). More recent analyses have used long-term exposure periods similar to commitment periods. In this analysis, 50 years was chosen for the value for EXPTIM, which defines the long-term exposure period.

3.4.2.3 *Evacuation, Sheltering, and KI Administration*

The following section is adapted from the protective action models developed and documented in reports prepared by SNL for the L3PRA project and in (Jones, Bixler and Kimura 2015). Evaluation of the technical bases for the recommendations provided by SNL allow for a methodology to be developed which is amenable to the development of scripted methods for developing initial estimates, which may then be reviewed by a subject matter expert. This approach significantly reduces the amount of manual interpretation of source term data needed. It also improves consistency and transparency by providing a traceable basis for the selection of specific parameter values and modeling choices

The site emergency plan calls for a variety of protective action recommendations, with recommended actions such as sheltering or evacuation out to different distances depending upon the emergency declarations and the projected doses. Offsite emergency plans state that distribution of potassium iodide (KI) is included as a protective action for site personnel and emergency workers only, therefore the KI model, represented by the variable KIMODL, was turned off in the analyses of consequences to the public.

Sheltering and evacuation in MACCS are defined based on a timeline that begins at accident initiation. The model assumes that notification of the public and sheltering activities occur first followed by evacuation. For each of the three MACCS evacuation movement phases (early, middle, and late), the user defines the travel speed of the evacuees. As cohorts traverse the defined path, their speed can be adjusted, as appropriate, to transition from one phase to the next. In order to ensure all individuals leave the evacuation region, the final evacuation movement phase is considered to last as long as necessary for all evacuating individuals to leave the region. The basic timeline for modeling evacuation is as follows:

- Accident initiation; public carrying out normal activities
- Notification of the public by offsite response organizations to take protective actions
- Period of sheltering prior to evacuation
- Period of active evacuation until the residents exit the analysis area and are assumed to receive no further dose

Prior to the beginning of evacuee movement, the MACCS emergency-response timeline is defined by the variables OALARM, DLTSHL, and DLTEVA. OALARM is a reference point from which protective actions are implemented in the MACCS code. DLTSHL represents a delay from the time of the start of the accident until a cohort begins to shelter. This period covers time for a protective action recommendation to the offsite response organization, notification of the public to evacuate by the offsite response organization, and the time needed to begin sheltering.

The shelter is typically assumed to be a place of residence. DLTEVA defines the length of the sheltering period from the time a cohort enters the shelter until the cohort begins to evacuate. Delay to evacuation represents the shelter period, but may also reflect a delay in response to the evacuation order, a need to wait for the return of commuters, a need to wait for public transportation, a need to shut down operations prior to leaving work, etc.

The active evacuation phase is defined by establishing the region in which the evacuation is modeled, and is then specified by defining evacuation phase durations and associated speeds, together with a definition of the path along which the evacuees travel.

Definition of Evacuation Zones and Network

The analysis uses a network evacuation model that can simulate the route and speed of evacuees as they undertake their evacuation. It also uses a keyhole evacuation model that preferentially evacuates populations in the downwind direction based on changes in wind direction. The NUMEVA variable defines the number of concentric rings that determines which residents can be modeled as subject to sheltering and/or evacuation. For this analysis, this limit is set at 25 miles to account for potential for a shadow evacuation beyond the largest official evacuation order modeled in the analysis. This corresponds to ring 25. The distance over which those populations travel prior to exiting the analysis area (and therefore receiving no further dose) is defined by the variable LASMOV. The distance is chosen to be 50 miles from the point of release, which corresponds to ring 28. One evacuation network was developed and used for all accident sequences. The MACCS network evacuation model was designed to represent travel direction and speeds along evacuation routes identified in the site ETE, as supplemented by additional work carried out by SNL to model the evacuation of the population from 10-15 miles and 15-20 miles. The evacuation area was mapped onto the MACCS grid. Evacuation speeds were developed from evacuation time estimates developed with the use of the traffic models. The recommended TRAVELPOINT for evacuees is the center of the grid element.

As discussed in Section F of Appendix I of NUREG-0396 (NRC 1978), offsite protective actions may be needed beyond the emergency planning zone in the event of the large potential releases associated with a failure of the containment leading to a release to the atmosphere. To simulate the protective actions that are expected to be undertaken by the offsite response organizations, this analysis has established three emergency-response templates, based on the magnitude and timing of the release. These templates provide for a 0–10 mile evacuation (Model EP1); a 0–10 mile evacuation followed by a 10-15 mile evacuation (Model EP2); or a 0–10 mile evacuation followed by a 10-20 mile evacuation (Model EP3). Models EP2 and EP3 also have a variant which may include a schools cohort, depending upon source term timing (Models EP2S and EP3S) These templates were then supplemented with the characteristics of specific source terms to develop the complete emergency-response model for this analysis.

Evacuation timing and speeds

Versions of the MACCS code prior to version 3.10 only allowed for a single value of OALARM. For earlier analyses with simpler protective action models, all offsite protective actions were

assumed to be initiated by the time of the general emergency declaration, providing a straightforward technical basis for the assignment of this variable. However, when offsite protective actions may be triggered for different cohorts at different points in time after the release, use of a single reference value is problematic. Note, MACCS does allow the value of DLTSHL to be defined on a cohort-specific basis. Furthermore, protective actions are taken offsite at a time defined only by the sum of OALARM and DLTSHL. Therefore, cohort-specific timings may be assigned by assigning OALARM to a value of zero (i.e., it is simultaneous with accident initiation) and including the cohort-specific evacuation order time along with the cohort-specific time needed to take shelter after an evacuation order is given. As such, in this analysis, OALARM is set to 0 and the DLTSHL variable includes the elapsed time from accident initiation until the population has begun sheltering. The cohort-specific value of DLTSHL from the appropriate EP model template is then added to the source-term-specific value of the evacuation order time to yield a combined delay to shelter that is both cohort and source-term-specific. The length of the sheltering period (DLTEVA), and all subsequent durations (DURBEG and DURMID), are assumed to be independent of the source term. In addition, the values for specific cohorts did not vary based on which evacuation template was appropriate. For example, the delays and speeds for the EPZ tail did not depend on whether the evacuation model included an expanded evacuation. Because the cohort-specific values were only a function of that cohort, this revision of the project used a single template to represent all possible evacuation models. The selection of an evacuation model was implemented by assigning the appropriate population to each cohort using the SUMPOP option. For example, for EP model 1 (a 0–10 mile evacuation only), a response template was defined for cohorts representing general public evacuees in the 10-15 mile and 15-20 mile region. However, no population was assigned to these cohorts in model EP1; therefore, any results that depend on the population of a cohort would be zero for those cohorts.

For each cohort, MACCS requires three evacuation speeds corresponding to the three evacuation phases. The duration of each phase is defined by DURBEG and DURMID. The duration of the beginning phase is typically the first few minutes of the evacuation, as motorists are just entering the evacuation network and beginning their evacuation. The duration is adjusted based on the cohort-specific attributes. The duration of the middle phase is assigned uniquely for each cohort. This is typically assigned a time value such that DURBEG plus DURMID provides sufficient time for the cohort to exit the evacuation zone. The remainder of time for individuals to complete their travel is considered the late-phase evacuation period. The evacuation speed for each of these three phases (ESPEED Early, ESPEED Middle, and ESPEED Late) is based on the traffic models used to develop the evacuation time estimates. For the late phase, a speed of 30 mph was applied to all cohorts. At this point in the evacuation, evacuees are well beyond the evacuation zone where traffic is less congested, and 30 mph represents a reasonable free-flow speed. After speeds were established for the roadways, adjustment factors were applied using the ESPGRD parameter at the grid level to increase speeds in the rural uncongested areas and slow speeds in the localized urban settings beyond the EPZ. For this analysis area, adjustments were only found to be necessary around the larger urban areas in the event of large releases that would result in relatively large numbers of evacuees.

The total ETE for the expanded evacuation area includes the time for notification and mobilization of the public and time to travel out of the analysis area. Notification within the EPZ occurs via sirens and tone alert radios. Most of the public becomes aware of the emergency within a few minutes. Notification beyond the EPZ is a process that requires resources and an organized approach to route alert the entire area, implement reverse 911 calling, and initiate emergency alert system messaging. The areas beyond the EPZ do not have an established siren system, and there is no preplanned emergency-response protocol for a nuclear power plant accident. However, the counties and the states do have all-hazards emergency-response plans which would be implemented. These plans include route alerting, use of emergency alert system messaging, and other means to notify the public that an emergency exists and provide direction on the actions to take. Route alerting for large rural areas would be a slow process. It is estimated to take 4 hours to notify the 10-15 mile area (392 square miles) and 6 hours to notify the 15-20 mile area (550 square miles). These values consider that media broadcasts of the nuclear emergency would have been ongoing prior to initiating expanded protective action. Authorities in the expanded action areas have time to plan the route alerting and obtain necessary resources. The public in the expanded areas would be largely aware of the nearby emergency. Such awareness would likely cause a percentage of the public to begin preparations to evacuate. Furthermore, the shadow population beyond the expanded evacuation area would also likely begin to prepare. This is expected to contribute to the shadow evacuation responding earlier than the initial shadow evacuees from the EPZ evacuation. This is reflected in a decrease in the time for the shadow evacuation to begin for each of the expanded evacuation scenarios.

For the EPZ, the following normal weather weekday scenario ETEs are obtained from the mobilization and evacuation curve in the site-specific ETE:

- 30-percent evacuation: 40 minutes
- 60-percent evacuation: 1 hour
- 90-percent evacuation: 1 hour and 40 minutes
- 100-percent evacuation: 3 hours and 20 minutes

The total ETEs recommended by SNL supporting reports for the areas beyond the EPZ, rounded to the nearest 15 minutes, are provided below:

10-15 mile area

- 90-percent evacuation: 6 hours
- 100-percent evacuation: 7 hours and 30 minutes

15-20 mile area

- 90-percent evacuation: 8 hours and 45 minutes
- 100-percent evacuation: 10 hours and 45 minutes

The site emergency plan calls for a keyhole evacuation, and therefore the analysis assumes that the initial protective action directs the population within the 5-mile radius to evacuate first together with downwind sectors in the 5-10 mile area. MACCS allows modeling of a keyhole evacuation and can expand the keyhole in advance of a wind shift to account for weather forecasting. The model knows the wind directions that will occur and expands the size of the keyhole accordingly, maintaining existing protective actions and initiating protective actions based on the wind shift. If the wind shifts, the evacuation is expanded radially to include additional sectors. The keyhole model is applied to cohorts representing the general public under evacuation orders. For special facilities (schools and industrial workers), as well as members of the general public who voluntarily evacuate without an evacuation order (i.e., shadow evacuation cohorts), a circular evacuation model was applied, meaning that these cohorts will evacuate at the designated times, rather than waiting for a wind shift. The MACCS parameter that controls the predictive weather feature in MACCS is KEYFORCST. When this feature is employed, the number of hours of weather forecasting is specified. The state radiological emergency plans describe an extensive supply of current meteorological information and forecasts during an emergency. Past, present, and future information can be obtained and staff are trained to ensure that important information is readily available. Onsite and offsite response procedures identify the availability and use of forecasted weather data; therefore, KEYFORCST was set to 3 hours. The width of the keyhole is defined by the variable NSECTR, which provides the width of the keyhole in terms of MACCS sectors. This was set at a value of 13, representing a keyhole width of 73 degrees, or about one-fifth of the full circle.

Adverse weather is addressed in the analysis using the evacuation speed multiplier (ESPMUL) in MACCS to reduce travel speed when precipitation is occurring. The ESPMUL factor was set at 0.85, which effectively slows the evacuating vehicles to 85 percent of the evacuation travel speed when precipitation exists. This value was developed from the site-specific ETE information where adverse weather for heavy rain was assumed to reduce free-flow speed by 15 percent. Although snow and ice are possible in the area, they are infrequent. A review of the NCDC storm events database showed five ice storm events between 2002 and 2014 (i.e., on the order of one reported event every other year), with ice accumulations ranging from ¼-inch to 1 inch. Because the accident sequences are not initiated by snow or ice, the likelihood that an internally initiated event would occur simultaneously with the presence of ice/snow-related adverse weather conditions is expected to be very low. The potential for a weather-related (particularly snow- and ice-related) loss of offsite power is one possibility for a situation in which the initiating event could be correlated to the travel conditions; however, sufficient information on specific weather conditions from the Level 1/2 analyses was not considered to be readily available to assess this potential correlation in a rigorous way.

Adjustment of Model Templates for Individual Source Terms

The source terms and the projected population distributions affected by different protective actions were used to develop protective action input parameters on a source-term-specific basis, where appropriate. The base-case model includes cohorts for the general public, including four cohorts for each spatial interval for which evacuation time estimates were developed (0–10, 10-15, and 15-20), shadow cohorts corresponding to each of these intervals,

and special populations. The special populations include provision for the industrial workers across the river from the site and provision for the large school population in and around the county seat, which is just outside the 10-mile EPZ.

The methodology for determining early- and intermediate-phase protective actions consists of the following steps:

- Determine the extent of evacuation and relocation by estimating the size and geographic extent of potential early- and intermediate-phase PAG exceedance
- Identify the range of potential evacuation orders based on the geographic extent of early-phase PAG exceedance
- Identify the time at which different evacuation orders (EPZ or expanded) would be recommended
- Estimate the time required for early-phase relocation based on the size of the evacuation zone and the projected size of the population requiring early-phase relocation

These steps are described in more detail in the following sections.

The first step in the process is to run a simplified analysis consisting of a single non-evacuating cohort. The result of that analysis is an estimate of the size of the population subject to normal and hotspot early-phase relocation (i.e., exceeding the early phase PAG levels of 1-5 rem in 4 days) as a function of distance from the site, as well as the size of the population subject to intermediate-phase relocation (i.e., exceeding the intermediate phase PAG of 2 rem in 1 year), for each source term. The population sizes provide an indication of the range at which early and intermediate-phase PAGs may be exceeded, as well as the size of the population subject to early and intermediate-phase PAGs. The second step in the process is to determine the size of the evacuation zone, which will determine the specific cohorts to be used for each source term. Based on the model documented in SNL L3PRA supporting reports, a total of five base-case emergency-response models (i.e., collections of cohorts) were developed. These are listed in Tables 3.4-5 and 3.4-13.

Table 3.4-13: Identification of base-case emergency-response models

EP Model	Description
1	Evacuation of full EPZ (~10-mile radius). No further evacuation orders beyond 10 miles. School cohorts in the 10-15 mile region are not included.
2, 2S	Evacuation out to 15-mile radius. Depending upon the timing of the event, a separate school cohort may or may not be included.
3, 3S	Evacuation out to 20-mile radius. Depending upon the timing of the event, a separate school cohort may or may not be included.

To determine the size of the evacuation zone, the distance to which hotspot (corresponding to 5 rem in 4 days) and normal (corresponding to 1 rem in 4 days) relocation would be needed for 90 percent of the population was estimated. This distance was used as a surrogate for the range at which PAGs would be projected to be exceeded. For most release categories, this results in less than 10 percent of the population subject to early-phase doses greater than 1 rem outside

the modeled evacuation zone. Since this is typically a small population relative to the much larger population within the 5-mile interval beyond the evacuation zone, and since the MACCS hotspot and normal early-phase relocation models will evacuate these populations relatively quickly in the early phase, this is considered a reasonable assumption for to avoid modeling the evacuation of unrealistically large areas. Note that this analysis assumed normal activity shielding factors, which may tend to limit the size of the population that exceeds PAG levels.

According to discussions with local offsite response organizations, schools may be evacuated in preparation to serve as shelters rather than simply dismissed. It is assumed that schools would not be opened if the plant is under an Alert or SAE, which typically occurs within an hour or less after accident initiation for most of the sequences evaluated here. It is assumed that schools would be evacuated rather than dismissed for scenarios in which an SAE is declared within 5 hours of accident initiation and in which a GE would be declared within 3 hours after SAE. This includes cases 1 and 7 (station blackout [SBO] cases), and cases 5B and 5D (interfacing systems LOCA [ISLOCA] cases with double-ended breaks). It is assumed that these schools would be evacuated 90 minutes after SAE for these cases. In the remaining cases, it is assumed that schools would have been dismissed normally (i.e., students would evacuate with their parents), and therefore no schools cohort is modeled. There are a few long-term SBO cases (Cases 1, 1A, and 1A1) in which an evacuation beyond the EPZ is not projected, but which otherwise meet the criteria for inclusion of a schools cohort due to the EAL timings. A separate schools cohort was not developed for these cases as the doses beyond 10 miles would not be expected to exceed PAG levels. The decision on whether or not to include a separate schools cohort is a source of uncertainty. Given that this cohort will be modeled as departing early, and constitutes a relatively large fraction of the 10-15 mile population, inclusion of a schools cohort is expected to result in lower results for collective effects, or for population-weighted effects, within the 10-15 mile area. However, it is not expected to impact any of the results within 10 miles, and is not expected to be a significant contributor to collective effects at distances of 50 miles or greater. As discussed in Section 3.4.4, a sensitivity analysis could be carried out to determine the impact of explicitly modeling a schools cohort.

The next step is to identify the evacuation order timing. It is assumed that all conditions involving a GE will result in an order to evacuate the full EPZ. The order to evacuate is assumed to be transmitted to the general public 45 minutes after a GE is declared. The timing of the decision to recommend evacuation beyond the 10-mile EPZ is subject to more uncertainty. The issuance of a PAR recommending evacuation beyond the EPZ would be based on dose projections. It is assumed that dose projections would show the potential for PAG exceedance beyond 10 miles for sequences with fuel damage coupled with total containment failure or for sequences with severe core damage coupled with a major leak in containment (see Table C-1 of [McKenna et al. 1996]). Therefore, the key determinant in the timing is identification of the time at with the containment function would not be credited in a dose assessment. For scenarios in which instrumentation can be assumed to be available (primarily non-SBO events), and containment is lost because of bypass events (ISLOCAs and SGTRs) or containment isolation failures, it is assumed that dose projections will be used to identify the potential for PAG exceedance beyond the EPZ within 1 hour of core damage. For these scenarios, the public is assumed to be notified to begin the expanded evacuation (either to 15 or 20 miles)

1.75 hours after core damage (defined in this analysis as the time at which peak cladding temperature exceeds 2200°F). The timings of the remaining cases are somewhat more challenging. It is assumed that loss of power in SBO events would hinder the ability to monitor in-containment conditions, but that the large releases from containment would be recognized shortly after they began and the dose significance readily understood. The remaining cases are transients for which dose projections may reveal the potential for PAG exceedance beyond the EPZ at any time between core damage and containment failure. For both of these scenarios, the public is assumed to be notified to begin the expanded evacuation 1.75 hours after containment failure. This comprises 1 hour to diagnose the release, perform dose assessments, and develop a PAR, and 45 minutes after the PAR determination is made to transmit the evacuation order to the general public.

An alternative to basing the expansion time recommendation off of indications of actual containment failure for these scenarios would be to assume that the recommendation to expand the evacuation would be made in an anticipatory fashion based on indications of severe challenges to containment coupled with indications of core damage. Use of this approach could provide several hours of additional warning time. When coupled with the time needed for the plume to travel beyond the 10-mile EPZ, use of the alternative approach for expansion time recommendations could result in evacuation of the 10-15 mile or 10-20 mile area before plume arrival, therefore reducing exposures in the 10-20 mile region.

The delays to shelter and evacuation for individual cohorts once warning has been provided, as discussed in the preceding paragraphs, as well as the evacuation phase durations and speeds, are based on the templates developed by SNL. These template values (with the exception of the delay to shelter [DLTSHL] variable, as discussed previously), are given in table 3.4-14. The DLTSHL values for each cohort and each source term, which include the declaration time as well as the mobilization time, are given in Table 3.4-16. The declaration times in Table 3.4-15 are subject to uncertainty.

Table 3.4-14: Emergency response template

#	Short Name	Description	EVAKEY	Delay to Shelter (DLTSHL)	Delay to Evac (DLTEVA)	DUR BEG (hr)	DUR MID (hr)	ESPEED1 (early) (mph)	ESPEED2 (mid) (mph)
1	1GP1	0–10 mile general public, first 30%	KEYHOLE	0.25[1]	0.25	0.25	0.25	25	25
2	1GP2	0–10 mile general public, second 30%	KEYHOLE	0.25[1]	0.50	0.25	0.25	25	25
3	1GP3	0–10 mile general public, third 30%	KEYHOLE	0.50[1]	1.00	0.17	0.17	25	25
4	1GPT	0–10 mile general public, final 10% (tail)	KEYHOLE	2.00[1]	1.00	0.17	0.17	25	25
5	IND	Industrial facility workers	CIRCULAR	0.00[1]	2.75	0.50	0.50	5	15
6	1GPS	10-15 mile general public shadow evacuees	CIRCULAR	1.00[1]	1.00	0.25	0.25	30	30
7	2GP1	10-15 mile general public, first 30%	KEYHOLE	0.5[3]	0.75	0.17	0.17	25	25
8	2GP2	10-15 mile general public, second 30%	KEYHOLE	1.5[3]	1.5	0.25	0.50	20	15
9	2GP3	10-15 mile general public, third 30%	KEYHOLE	3.5[3]	1.75	0.25	0.50	10	5
10	2GPT	10-15 mile general public, final 10% (tail)	KEYHOLE	4[3]	2	0.25	1.25	5	5
11	SCH	10-15 mile schools	CIRCULAR	0.50[2]	1.00	0.25	0.25	25	25
12	2GPS	15-20 mile general public shadow evacuees	CIRCULAR	1.00	1.00	0.25	0.25	20	20
13	3GP1	15-20 mile general public, first 30%	KEYHOLE	1.00[3]	2.00	0.25	0.50	20	10
14	3GP2	15-20 mile general public, second 30%	KEYHOLE	2.50[3]	2.50	0.50	0.50	10	10
15	3GP3	15-20 mile general public, third 30%	KEYHOLE	4.50[3]	2.50	0.25	1.50	10	5

Table 3.4-14: Emergency response template (continued)

#	Short Name	Description	EVAKEY	Delay to Shelter (DLTSHL)	Delay to Evac (DLTEVA)	DUR BEG (hr)	DUR MID (hr)	ESPEED1 (early) (mph)	ESPEED2 (mid) (mph)
16	3GPT	15-20 mile general public, final 10% (tail)	KEYHOLE	6.00[3]	2.75	2.00	0.25	5	10
17	3GPS	20-25 mile general public shadow evacuees	CIRCULAR	1.00[3]	1.00	0.25	0.50	20	20
18	NE	Non-evacuees	NONE	n/a	n/a	n/a	n/a	n/a	n/a

[1]DLTSHL is added to the EPZ notification time given in Table 3.4-15.
[2]DLTSHL is added to the SAE declaration time given in Table 3.4-15.
[3]DLTSHL is added to the expanded evacuation warning time given in Table 3.4-15.

Table 3.4-15: Case specific declaration times for model expansions

Release Category	Source Term	EP Model	SAE Declaration (hr)	GE Declaration (hr)	EPZ (0–10 mile) Notification time (hr)	Expanded Evacuation (10-15 or 10-20 mi) Notification time (hr)	Basis for Evacuation Expansion[1]
V-F	5D	3S	0.25	1.25	2	4.55	CD+B
V-F-SC	5B	3S	0.25	1.25	2	4.55	CD+B
V	5	1	0.25	7.5	8.25	n/a[2]	n/a
SGTR-O	8B	3	38	47	47.75	51.75	CD+B
SGTR-O-SC	8BR1	3	38	47	47.75	51.75	CD+B
SGTR-C	8	3	38	47	47.75	51.75	CD+B
ISGTR	3A2	3	5	8	8.75	12.75	CD+B
CIF	7	3S	0.25	3	3.75	17.75	CD
CIF-SC	7A	3S	0.25	3	3.75	17.75	CD
ECF	2A	3	7	8	8.75	23.75	CF
LCF	1B	2S	0.25	3	3.75	49.75	CF
LCF-SC	2R2	1	7	8	8.75	n/a[2]	n/a
ICF-BURN	1A2	3S	0.25	3	3.75	29.75	CF
ICF-BURN-SC	1A2_TR28	1	0.25	3	3.75	n/a[2]	n/a
BMT	6	1	13	13	13.75	n/a[2]	n/a
NOCF	2R1	1	7	8	8.75	n/a[2]	n/a

[1] *Basis for Expansion Time Codes:*
CD: Time of core damage
CD+B: Time of core damage coupled with bypass failure
CF: Time of containment failure

[2] *for EP model 1, there is no expanded evacuation. A value of 216 hrs was used as a placeholder value to allow construction of input files*

Table 3.4-16a: DLTSHL (hrs) for EP Model 1 cohorts

Release Category	Source Term	EP Model	0–10 Public 1st group	0–10 Public 2nd group	0–10 Public 3rd group	EPZ Evacuation Tail	Industrial Facility Workers	10-15 Shadow
V-F	5D	3S	2.25	2.25	2.5	4	2	3
V-F-SC	5B	3S	2.25	2.25	2.5	4	2	3
V	5	1	8.5	8.5	8.75	10.25	8.25	9.25
SGTR-O	8B	3	48	48	48.25	49.75	47.75	48.75
SGTR-O-SC	8BR1	3	48	48	48.25	49.75	47.75	48.75
SGTR-C	8	3	48	48	48.25	49.75	47.75	48.75
ISGTR	3A2	3	9	9	9.25	10.75	8.75	9.75
CIF	7	3S	4	4	4.25	5.75	3.75	4.75
CIF-SC	7A	3S	4	4	4.25	5.75	3.75	4.75
ECF	2A	3	9	9	9.25	10.75	8.75	9.75
LCF	1B	2S	4	4	4.25	5.75	3.75	4.75
LCF-SC	2R2	1	9	9	9.25	10.75	8.75	9.75
ICF-BURN	1A2	3S	4	4	4.25	5.75	3.75	4.75
ICF-BURN-SC	1A2_TR28	1	4	4	4.25	5.75	3.75	4.75
BMT	6	1	14	14	14.25	15.75	13.75	14.75
NOCF	2R1	1	9	9	9.25	10.75	8.75	9.75

Table 3.4-16b: DLTSHL (hrs) for EP Model 2 additional cohorts

Release Category	Source Term	EP Model	10-15 Public 1st group	10-15 Public 2nd group	10-15 Public 3rd group	10-15 Evacuation Tail	10-15 Schools	15-20 Shadow
V-F	5D	3S	5.05	6.05	8.05	8.55	0.75	5.55
V-F-SC	5B	3S	5.05	6.05	8.05	8.55	0.75	5.55
V	5	1	*216.5*	*217.50*	*219.50*	*220.00*	*0.75*	*217.00*
SGTR-O	8B	3	52.25	53.25	55.25	55.75	38.50	52.75
SGTR-O-SC	8BR1	3	52.25	53.25	55.25	55.75	38.50	52.75
SGTR-C	8	3	52.25	53.25	55.25	55.75	38.50	52.75
ISGTR	3A2	3	13.25	14.25	16.25	16.75	5.50	13.75
CIF	7	3S	18.25	19.25	21.25	21.75	0.75	18.75
CIF-SC	7A	3S	18.25	19.25	21.25	21.75	0.75	18.75
ECF	2A	3	24.25	25.25	27.25	27.75	7.50	24.75
LCF	1B	2S	50.25	51.25	53.25	53.75	0.75	50.75
LCF-SC	2R2	1	216.50	217.50	219.50	220.00	7.50	217.00
ICF-BURN	1A2	3S	30.25	31.25	33.25	33.75	0.75	30.75
ICF-BURN-SC	1A2_TR28	1	216.50	217.50	219.50	220.00	0.75	217.00
BMT	6	1	216.50	217.50	219.50	220.00	13.50	217.00
NOCF	2R1	1	216.50	217.50	219.50	220.00	7.50	217.00

Table 3.4-16c: DLTSHL (hrs) for EP Model 3 additional cohorts

Release Category	Source Term	EP Model	15-20 Public 1st group	15-20 Public 2nd group	15-20 Public 3rd group	15-20 Evacuation Tail	20-25 Shadow
V-F	5D	3S	5.55	7.05	9.05	10.55	5.55
V-F-SC	5B	3S	5.55	7.05	9.05	10.55	5.55
V	5	1	217.00	218.50	220.50	222.00	217.00
SGTR-O	8B	3	52.75	54.25	56.25	57.75	52.75
SGTR-O-SC	8BR1	3	52.75	54.25	56.25	57.75	52.75
SGTR-C	8	3	52.75	54.25	56.25	57.75	52.75
ISGTR	3A2	3	13.75	15.25	17.25	18.75	13.75
CIF	7	3S	18.75	20.25	22.25	23.75	18.75
CIF-SC	7A	3S	18.75	20.25	22.25	23.75	18.75
ECF	2A	3	24.75	26.25	28.25	29.75	24.75
LCF	1B	2S	50.75	52.25	54.25	55.75	50.75
LCF-SC	2R2	1	217.00	218.50	220.50	222.00	217.00
ICF-BURN	1A2	3S	30.75	32.25	34.25	35.75	30.75
ICF-BURN-SC	1A2_TR28	1	217.00	218.50	220.50	222.00	217.00
BMT	6	1	217.00	218.50	220.50	222.00	217.00
NOCF	2R1	1	217.00	218.50	220.50	222.00	217.00

Evacuation Costs

MACCS considers the economic impact of compensation for people who are subject to evacuation. The variable EVACST defines the daily cost of compensation for evacuees and residents displaced by the evacuation (Chanin and Young 1998a). The costs are incurred from the time of evacuation or relocation through the end of the early phase. The daily cost per person is user supplied and as described by (Jow et al. 1990) can include the cost of temporary lodging, meals, and lost income, although the per-capita daily cost of $24 used in NUREG/CR-3673 (Burke et al. 1984) did not include loss of personal or corporate income. Sprung et al. (1990) describes EVACST as per-diem living expenses for evacuees and escalated the estimate for per-diem relocation costs to 1986 for use in NUREG-1150. The (Burke et al. 1984) per-diem relocation costs were based on a 1974 EPA study of evacuation risks (EPA 1974), where the costs were weighted based on an assumption that 20 percent of the public stay in mass care facilities. However, the majority of people who evacuate their homes do not use public shelter facilities for overnight stay (Mileti 1992), with generally less than 10 percent staying in shelters (Dotson and Jones 2005). People most often stay with friends and relatives or in hotels. For those who evacuate, the costs of hotels and meals is a burden that would not have been incurred under normal conditions. There may be less personal cost for food and lodging for evacuees who stay with relatives and friends; however, there are tangible and intangible costs associated with staying with family, thus the lodging costs for this analysis assume Federal per-diem rates for all. The rates for the nearest metro area where large amounts of temporary housing may be available, were used. The 2015 per diem is $135/person-day[18] and $56 meals and miscellaneous expenses. It is assumed one household would use one hotel room. According to the U.S. Census Bureau,[19] the 2010 census shows 300.8 million persons living in 116.7 million households, for an average household population of 2.58 persons per household. Assuming that one household occupies one hotel room, the lodging costs are converted to a per-capita basis by dividing the lodging allowance by 2.58 (number of persons per household in the U.S.) for a lodging cost of $52 per person-day. For this analysis, lost income was included in the computation of EVACST, as suggested by (Jow et al. 1990). The average per-capita lost income of $78.16 per day is based on a 2015 Employment-Population Ratio of 59.4 percent[20] and a 2015 National Average Wage Index of $48,098.63.[21] The total per person-day cost (expressed in 2015$) for EVACST is the sum of the above ($52 + $56 + $78), which equals $186 (rounded to $190) per person per day.

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[18] http://www.gsa.gov/portal/category/100120

[19] "Households and Families: 2010," https://www.census.gov/prod/cen2010/briefs/c2010br-14.pdf, accessed 7 May 2015.

[20] https://data.bls.gov/timeseries/LNS12300000

[21] https://www.ssa.gov/oact/cola/AWI.html

An alternative value, and potentially somewhat more site-specific value, can be derived using data from the U.S. census[22] that indicates a per-capita income from 2008 to 2012 of $23,906 to $25,309 for the two states comprising the EPZ, and a statewide standard rate of $83 for lodging and $46 for meals and incidentals. This results in an average daily per-capita value of lost income of $67. Escalated to 2014 using the BLS CPI calculator[23] results in an average daily per-capita value of lost income of $70. Per-capita lodging costs would be $32 and per-capita meals and incidentals would be $46, for a total per-diem cost of $148.

Alternatively, escalation of the values from NUREG-1150 from 1986 until 2015 using an escalation factor of 2.14 would result in $58 per day, which is substantially lower than the values here due to the exclusion of lost income, as well as the assumptions regarding lodging (20 percent of the evacuees in mass care, and the remaining 80 percent lodging in rooms at four persons per room).

Given the uncertainties associated with the inclusion of lost income, the occupancy rate, and the food costs, the value could range from $60 to $190 per person per day.

A summary of the parameters used to model KI administration, sheltering, and evacuation is provided below in Table 3.4-17.

Table 3.4-17: Summary of KI, sheltering, and evacuation parameters

MACCS Variable	Description	Value	Comment
KIMODL	Model Flag for KI Ingestion	NOKI	
EVATYP	Radial or network model flag	NETWORK	
KEYAVAIL	Indicates whether keyhole evacuation is used for possible evacuation	KEY_AVAIL	
EVAKEY	Evacuation algorithm	Table 3.4-14	Varies by cohort
KEYFORCST	Hours of forecast weather available	3	
NSECTR	Number of sectors in keyhole	13	
KEYDIS	Radius of circular area of keyhole	9	Ring 9 coincides with 5 miles
NUMEVA	Number of radial elements comprising the sheltering and evacuation region	25	Ring 25 coincides with 25 miles
LASMOV	Outermost spatial interval of the evacuation movement zone	28	Ring 28 coincides with 50 miles
TRAVELPNT	Boundary or Centerpoint	CENTERPOINT	

22 http://quickfacts.census.gov/qfd/index.html#

23 http://www.bls.gov/data/inflation_calculator.htm

Table 3.4-17: Summary of KI, sheltering, and evacuation parameters

MACCS Variable	Description	Value	Comment
REFPNT	Reference time point for evacuation zone	ALARM	
DLTSHL	Delay to shelter	Table 3.4-16	Varies by sequence and cohort: All rings use same value
DLTEVA	Delay to evacuation	Table 3.4-14	Varies by cohort
DURBEG	Duration of the initial evacuation phase	Table 3.4-14	
DURMID	Duration of the middle evacuation phase	Table 3.4-14	
ESPEED	Travel speed of evacuees	Table 3.4-14	
ESPMUL	Speed multiplier during adverse weather	0.85	
ESPGRD_NET	Grid-dependent speed multiplier	Table A.3	
IDIREC	Destination direction of spatial elements	Table A.4	

3.4.2.4 *Relocation and Interdiction Model*

Relocation of the public as a protective measure was first introduced in the CRAC model to instantaneously remove the public from areas that exceed specified dose limits and has since evolved in the MACCS code to include hotspot, normal, and intermediate-phase relocation. MACCS provides the ability to implement relocation in the early phase as well as the intermediate phase, while EPA typically describes relocation as occuring during the intermediate phase (EPA 2013). MACCS also includes the ability to simulate temporary or permanent interdiction, which is modeled in a manner consistent with relocation based on habitability criteria for the recovery phase.

The MACCS early-phase relocation is implemented by the MACCS hotspot and normal relocation criteria. Relocation times depend on the source term and on the size of the population affected. Larger source terms would trigger relocation farther from the plant than smaller source terms and areas with larger population would take longer to notify and to relocate than those with a smaller population. Likewise, as discussed in Section 3.4.2.2, the intermediate phase would likely last longer for larger releases.

The “critical organ” for the EARLY and CHRONC phase (CRIORG and CRTOCR, respectively) is the dosimetric quantity used to determine when certain protective actions should be taken. Staff chose MACCS dosimetric quantity L-ICRP60ED to represent this quantity for both the EARLY and CHRONC phase critical organs because it is an effective dose analogous to doses used to evaluate the need for protective actions. The tissue weighting factors to calculate an

effective dose are based on ICRP-60 and are consistent with FGR-13, as discussed in Section 3.5.

Early-Phase Relocation (EARLY)

Early-phase relocation (which in MACCS is accomplished by limiting the exposure duration) is a protective measure that is expected to be implemented in areas where residents would exceed a specified dose threshold. In MACCS, this model is applied to the entire non-evacuating cohort, whether they are located within or outside of the evacuation zone. Relocation may be implemented due to exceedance of the EPA early-phase PAGs or because localized levels of contamination are higher than surrounding areas, resulting in areas that may exceed the EPA PAG for evacuation. Depending on the release characteristics, terrain, weather, and other conditions, localized levels of contamination can result in areas with elevated dose rates. Relocation was first introduced in the CRAC model to instantaneously remove the public from areas that exceeded specified dose limits (NRC 1975) at a specified time after plume arrival. In WASH-1400, this was applied beyond the modeled 25-mile evacuation zone assumed in that study:

> "If the ground contamination were sufficiently large to warrant relocation of people, it is assumed that such relocation will be accomplished within an average period of 7 days. If rain were to result in an unusually high ground contamination within a small area, the population within such an area is assumed to be evacuated within an average of 24 hours." (page 11-30 of [NRC 1975])

The early relocation from areas affected by rain beyond 25 miles has evolved into the current early-phase hotspot and normal relocation models. These models therefore appear to be analagous to a targeted evacuation of hotspots beyond the sheltering and evacuation zone modeled in MACCS, rather than the relocation that is implemented at the beginning of the intermediate phase (i.e., after a period defined by ENDEMP). NUREG-1150 used a model in which a projected whole body effective dose of 50 rem in 1 week triggered relocation of non-evacuees at 12 hours after plume arrival, and a projected whole body dose of 25 rem in 1 week triggered relocation at 24 hours after plume arrival. However, the rationale for this model was not provided. The relocation models in SOARCA were keyed to the EPA evacuation criteria of 1-5 rem,[24] rather than the higher limits of 25-50 rem used in NUREG-1150. According to NUREG-7009 (Bixler et al. 2014), "The relocation times used in SOARCA were 12 hours for hotspot and 24 hours for normal relocation for Peach Bottom and 24 hours for hotspot and 36 hours for normal relocation for Surry. The values for Surry are longer than Peach Bottom because the population density is greater and the area north and east of the plant is heavily urban. This would require additional resources to notify residents and support relocating them

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[24] For Peach Bottom, the Pennsylvania intermediate phase relocation dose criterion of 500 mrem was used as the dose criterion for normal relocation.

out of the affected area. Notifying and relocating the larger population would be expected to take a longer time."

The use of the term relocation to describe the MACCS early-phase protective actions outside the evacuation zone may be somewhat confusing. The EPA provides PAGs for relocation (EPA 2013); however, the EPA PAGs are for implementation during the intermediate phase (EPA 2013), and are for a different use than the hotspot and normal relocation which are implemented in the early phase in MACCS. The protective actions described as relocation in EPA guidance are implemented in MACCS by the criteria for intermediate-phase relocation. The MACCS early-phase relocation model is consistent with an expanded evacuation of hotspot areas exceeding evacuation criteria beyond the initial evacuation zone. Therefore, it is based on the EPA early-phase criteria for evacuation or sheltering, which is "a projected whole body dose of 1 to 5 rem (10 – 50 mSv) total effective dose (TED) over four days" (EPA 2013).

The determination of areas requiring such early relocation likely would be based on dose projections from state, utility, and federal agency computer modeling, coupled with field measurements. Onsite and offsite emergency plans provide that field teams are dispatched very early in an event to take field measurements and track plumes on the ground. Along with the results of dose assessments, this information is available to OROs to make informed decisions regarding the potential need to relocate residents. In consequence analyses, this protective measure can be simulated within MACCS as an expanded evacuation based on dose projections, which could occur relatively quickly, or as a post-deposition relocation based on field surveys, which could require more time to complete. In practice, the implementation of such an expanded evacaution may fall somewhat between these two limits, due to conflicting priorities during a response. Determining the most appropriate values for these MACCS parameters requires a level of judgment involving site-specific information, accident scenario timing information, and knowledge of response activities. Project staff developed the process below to provide an approach consistent with an expanded evacuation based on dose projections supplemented with confirmatory field measurements. The potential for conflicting priorities during a response could cause actual times to differ.

In this analysis, hotspot and normal evacuation are estimated using a process adapted from (Jones, Bixler, and Kimura 2015). The hotspot and normal evacuation times in MACCS can be developed to simulate a preemptive evacuation order, in which it is assumed that relocation activities would be initiated prior to plume arrival based on dose projections. Alternatively, these evacuation times can be developed to simulate relocation based on post-deposition field measurements, in which it is assumed that relocation activities would be initiated after plume arrival.

The size of the evacuation zone was based on the potential for PAG exceedance. Therefore, in most cases, the size of the relocated population outside the evacuation zone is relatively small. For these cases, the relocation times were based on the assumption that the primary population affected by hotspot and normal relocation would be the non-evacuees (primarily within the evacuation zone). Therefore, timings were developed based on a reactive, post-deposition model. It is assumed in this approach that this relocation may be carried out concurrent with any

ongoing evacuation. The approach for modeling relocation of non-evacuees is based on an assumption regarding the time needed to identify areas requiring relocation, coupled with an estimate of the time needed to clear the area based on the site-specific ETE.

The time needed to identify areas subject to evacuation following plume arrival is assumed to be 4 hours, since field survey teams would be dispatched early in the event and would be guided by dose projection and meteorological information to facilitate rapid identification of hotspots. Since it is assumed that areas subject to hotspot relocation would mobilize and evacuate more rapidly than the less contaminated areas subject to normal relocation, the 90th percentile ETE estimate was assumed for hotspot relocation and the 100th percentile ETE estimate for normal relocation.

Some scenarios are characterized by a large number of projected relocatees beyond the modeled evacuation zone. These were typically scenarios with iodine release fractions greater than 1 percent. Iodine release fractions of greater than 1 percent, but less than about 10 percent, tended to yield a few thousand persons beyond the modeled evacuation zone subject to normal relocation, and none subject to hotspot relocation. In contrast, bypass events with iodine release fractions on the order of 10 percent or higher led to tens of thousands of persons subject to normal relocation, and several thousand subject to hotspot relocation. In these cases, the hotspot relocation time was assumed to be equal to the maximum hotspot relocation time, and the normal relocation time was assumed to require 24 hours. For these cases resulting in very large releases, it may be challenging to complete relocation of the entire affected population within the specified time periods. However, in these cases it is assumed that dose projections would be available to support a recommendation to shelter in areas where doses could be expected to exceed PAGs. There would be some additional protection associated with sheltering relative to normal activity (which is the code assumption used for setting shielding factors for the non-evacuating cohort), particularly in urban areas where more substantial buildings may be available for sheltering. For such sequences, the relocation times given herein may be more appropriately interpreted as an “effective” relocation time concept described by (Aldrich et al. 1979). Under this concept, a period of normal activity followed by a period of sheltering results in less dose than the same total period of normal activity; conversely, a brief period of normal activity followed by a long period of sheltering may yield the same dose as a short period of normal activity. Application of the process described above results in the relocation times shown in Table 3.4-18.

Table 3.4-18: Recommended early-phase relocation timing

EP Model	Evacuation Zone Radius (mi)	Assumed identification time (hr)	90^{th} percentile ETE (hh:mm)	100^{th} percentile ETE (hh:mm)	Hotspot Relocation Time (hr)	Normal Relocation Time (hr)
1	10	4	1:40	3:20	5.67	7.33
2/2S	15	4	6:00	7:30	10	11.5
3/3S	20	4	8:45	10:45	12.75	14.75
3/3S*	20	4	8:45	10:45	12.75	24

*Used for cases with more than 1,000 projected normal evacuation relocatees beyond the evacuation zone.

The results from this approach may be compared to the description of the original approach for estimating minimum relocation time as described in SNL project reports and (Jones, Bixler, and Kimura 2015). The sequence-specific hotspot values were developed with the following equation:

$$HS_T = Evac_T + ETE_{90} + R_T - P_{IR} - P_{TT}$$

Where:

- HS_T = hotspot relocation time after plume arrival
- $Evac_T$ = the time at which the evacuation is ordered for the last area evacuated
- ETE_{90} = the 90 percent ETE for the last area evacuated
- R_T = the time for the affected area to mobilize and move out of the area
- P_{IR} = the time of the initial plume release
- P_{TT}= the time for the plume to travel to the initial bounds of the affected area.

This equation calculates the minimum recommended hotspot relocation time. The approach considers that relocation of an area would not be implemented prior to evacuation of the area immediately adjacent. Once the evacuation of the area is substantially complete, OROs could focus efforts on potential hotspot areas. To estimate normal relocation time for these source terms, SNL staff recommended adding 6 hours to the hotspot relocation time. In order to implement this methodology, the following assumptions were made for purposes of comparison to the default approach:

- The warning time ($Evac_T$) for the last area evacuated is assumed to be the time of containment failure plus 1.75 hours, as described in Section 3.4.2.3.
- The time for the affected area to mobilize and move out of the area (R_T) is assumed to be the ETE_{90} evacuation time. If only the EPZ is modeled as evacuating, the time is assumed to be twice the EPZ ETE_{90}, in order to account for an assumed slower response outside of the EPZ.
- The time of initial plume release is assumed to be the time of containment failure
- The plume travel time is assumed to be the radius of the evacuation zone divided by an average wind of 5 mph

Using these assumptions, it can be seen that

$$\begin{aligned} HS_T &= Evac_T + ETE_{90} + R_T - P_{IR} - P_{TT} \\ &= 1.75+T_{CF} + ETE_{90} + ETE_{90} - T_{CF} - P_{TT} \\ &= 2^* ETE_{90}+1.75 - P_{TT} \end{aligned}$$

This approach gives values, shown in Table 3.4-19, that are reasonably consistent with the values shown in Table 3.4-18, which are based on the simplified approach described previously.

Table 3.4-19: Alternate early-phase relocation timing

EP Model	Evacuation Zone Radius (mi)	90th percentile ETE	Hotspot Relocation Time (hr)	Normal Relocation Time (hr)
1	10	1.67	4.8	10.8
2/2S	15	6.00	10.8	16.8
3/3S	20	8.75	15.4	21.4

Given the uncertainties involved in developing these time estimates, the sequence-specific values in Table 3.4-20 (based on the estimates provided in Table 3.4-18) were used in the L3PRA project. These values are uncertain, although the specific range in the parameters has not been defined. Actual relocation decisions based on field monitoring and aerial monitoring would have a high degree of accuracy. However, relocation likely would be accomplished similar to evacuation, where areas that are relocated are bounded by physical or geographical features.

Table 3.4-20: Early-phase relocation parameters

Release Category	Modeling Case	EP Model	Hotspot Relocation Time (hr)	Normal Relocation Time (hr)
ICF-BURN	1A2	EP3S	12.75	24
ICF-BURN-SC	1A2_TR28	EP1	5.67	7.33
LCF	1B	EP2S	10	11.5
ECF	2A	EP3	12.75	24
NOCF	2R1	EP1	5.67	7.33
LCF-SC	2R2	EP1	5.67	7.33
ISGTR	3A2	EP3	12.75	24
V	5	EP1	5.67	7.33
V-F-SC	5B	EP3S	12.75	24
V-F	5D	EP3S	12.75	24
BMT	6	EP1	5.67	7.33
CIF	7	EP3S	12.75	24
CIF-SC	7A	EP3S	12.75	24
SGTR-C	8	EP3	12.75	24
SGTR-O	8B	EP3	12.75	24
SGTR-O-SC	8BR1	EP3	12.75	24

MACCS also considers the economic impact of individuals relocated by hotspot or normal relocation by applying the cost defined for evacuees (EVACST, previously discussed in Section 3.4.2.3) to individuals relocated during the EARLY phase.

Intermediate-Phase Relocation and Recovery-Phase Interdiction (CHRONC)

Relocation in the intermediate phase is modeled similarly to the way it is modeled for the early phase. Individuals who are projected to exceed a dose threshold are relocated at the end of the emergency phase (ENDEMP). The critical organ for relocation decisions in both the intermediate phase and recovery phase is defined by the MACCS variable CRTOCR, which is chosen to be the effective whole body dose (L-ICRP60ED) for the project. The dose pathways included are groundshine and resuspension inhalation.

MACCS parameters DSCRTI, CRTOCR, and DPP_INTERPHAS define the intermediate-phase dose criterion, which is the maximum allowable equivalent dose (DSCRTI) to the long-term critical organ (CRTOCR) over the dose projection period (DPP_INTERPHAS). For the purpose of evaluating the need for intermediate-phase relocation, the total dose commitment is the dose that would be received by an individual who remained in place for the dose projection period for the intermediate phase (DPP_INTERPHAS) while engaging in normal activity. The dose projection period for the intermediate phase was defined as one year. If DSCRTI is exceeded at some location, the resident population is relocated for the entire intermediate phase period (Chanin and Young 1998a). The state radiological emergency plan refers to the EPA guidelines, which specify a protective action guide of 2 rem in the first year and 500 mrem in subsequent years. EPA explains that due to shielding, decay, and weathering, an initial 2 rem dose in the first year would likely reduce to 0.5 rem in subsequent years (EPA 2013). SNL staff therefore recommended that the dose projection period for the intermediate phase, DPP_INTERPHAS, be established as 1 year.

MACCS allows one value for DSCRTI, and to define the value, the duration of the intermediate phase and decontamination periods for the intermediate and long-term phases should be considered. Developing a specific criterion that captures these contributing influences is complex and requires a number of assumptions; therefore, a simplified approach is provided for this analysis. For cases where no intermediate phase is recommended, the long-term phase is entered immediately and there is no criterion for the intermediate phase. For the remaining cases, most of which have an intermediate phase duration of 12 months, the criterion is 2 rem over a 1-year dose projection period, which is consistent with the EPA PAG. For this analysis, there were no source terms without an intermediate phase. Therefore, DSCRTI was established as 2 rem for all source terms, to be consistent with the criteria of 2 rem in the year of the accident.

For the long-term (recovery) phase, interdiction functions similarly to the intermediate-phase relocation model. If individuals located in areas that were not evacuated, and did not exceed either the early- or intermediate-phase relocation criteria, are projected to exceed the habitability criteria, they are assumed to be relocated at the beginning of the long-term phase and receive no dose until they are allowed to return home. Protective actions, including decontamination and continued interdiction following decontamination, are evaluated to determine if exposure can be reduced, such that the long-term-phase-allowable dose (DSCRLT) to the long-term-critical organ (CRTOCR) is not exceeded for the long-term phase dose projection period (TMPACT). If temporary interdiction is required, individuals are returned to their homes at a time when it is

estimated that they receive a dose of DSCRLT to the critical organ over the dose projection period (Chanin and Young 1998a). Habitability decisionmaking in MACCS can result in several possible outcomes:

1. land is immediately habitable
2. land is habitable after decontamination
3. land is habitable after a combination of decontamination and additional interdiction

If the property cannot be made habitable within 30 years (or the farmland cannot be made farmable within 8 years), or if the cost to restore habitability of the property exceeds the cost to condemn it, the property is condemned and the resident population is permanently relocated. Therefore, individuals residing in these areas receive no dose, but incur an economic loss resulting from the condemnation of their properties.

For the long-term phase where recovery actions such as cleanup are undertaken, the EPA has not established numerical values for the habitability criteria, explaining that “Community members will influence decisions such as if and when to allow people to return home to contaminated areas. … Implicit in these decisions is the ability to balance health protection with the desire of the community to resume normal life. Radiation protection considerations must be addressed in concert with health, environmental, economic, social, psychological, cultural, ethical, political and other considerations” (EPA 2013). Therefore, the EPA does not provide quantitative criteria that can be used to establish the numerical criteria needed for DSCRLT. In ICRP Publication 111 (ICRP 2009), no specific reference level is provided. However, an observation is provided that a “reference level for the optimisation of protection of people living in contaminated areas should be selected in the lower part of the 1–20 mSv/year.”

Consistent with past practice, the project therefore applies EPA guidance for the intermediate phase as a surrogate for decisionmaking regarding long-term phase habitability. In previous analyses, such as NUREG-1150 and SOARCA, the habitability criterion was established as 4 rem in 5 years. In reviewing the application of this value, it became apparent that it is more appropriate to apply 2 rem in the first year after the emergency phase. For cases where no intermediate phase is recommended, the long-term phase is entered immediately and the long-term phase dose criterion (DSCRLT) was established based on the EPA guidance for the intermediate phase, which is 2 rem in the first year after the accident. However, all source terms in this analysis were projected to have a non-zero duration for the intermediate phase. Therefore, all cases were assigned a long-term dose criterion of 0.5 rem over a 1-year dose projection period (defined by TMPACT), which is consistent with the EPA intermediate-phase guidance for the years following the accident. For source terms with an intermediate phase duration of less than 1 year, this may overestimate the area subject to decontamination. However, such source terms are characterized by relatively limited decontamination efforts, such that this overestimate is not expected to be significant.

The MACCS model for assessing the cost of interdiction (either temporary or permanent) is based on the model described in Appendix 6 of WASH-1400 (NRC 1975). The costs associated with interdiction include both costs for relocation of the population, as well as costs associated

with loss of usage of the property during the period of interdiction. The MACCS model of these costs is described in Section 4.3.1 of (Jow et al. 1990), as well as in Chapter 5 of (Sprung et al. 1990).

Estimation of Relocation Costs

The intermediate-phase cost parameter RELCST, which reflects a daily cost, captures the compensation for people who are subject to relocation during the intermediate phase (Chanin and Young 1998a). The costs are incurred from the end of the EARLY phase to the end of the intermediate phase. The total duration is defined by the variable DUR_INTPHAS, as defined previously. The basis for RELCST differs from the basis for EVACST due to the longer term nature of the activity. As relocated residents find longer term housing, they would incur similar costs for meals as they would had they been at home; thus meals are assumed not to be an added cost burden to the household.

A review was conducted by SNL staff for lodging costs. Previous studies weighted the cost based on the percent of the public who went to shelters (EPA 1974). However, weighting the values is not entirely appropriate for extended stay under the evacuation or relocation criterion. If intermediate-phase relocation does occur, it is not likely for just a few days. A small percent of residents may go to shelters initially, but the number of evacuees staying in shelters would be expected to decrease as the duration increases. Families who rent their lodging may no longer need to pay rent for their original lodging, and would be paying rent for their new lodging. Thus, there would be no increased financial burden to the renter. However, apartment owners may have loans and homeowners would have mortgage debts even though their home cannot be used. Therefore, for the L3PRA project, lodging is fully included in the RELCST parameter to capture these cost burdens. The total per person-day cost for RELCST is therefore based on the lodging component and lost income of EVACST described in Section 3.4.2.3. In the current analysis, the lost income component of EVACST continues to be applied in the intermediate phase, as it is assumed that employment of relocatees would be disrupted during the period of intermediate-phase relocation. Based on the above considerations, the total per person-day cost for RELCST is the sum of the lodging and lost income components of EVACST. The value used for RELCST is therefore ($52 + $78), which equals $130 (in 2015$) per person per day.

For the long-term phase, the CHRONC input variable POPCST ($/person) defines a per person cost for temporary or permanent relocation of the population during a period of interdiction. This is considered to be a one-time cost in the MACCS model and is not dependent upon the length of the interdiction period. Staff considered two alternate approaches to deriving a value for POPCST, one based on the aspect of the lost income resulting from relocation, and one based on the cost of moving of household goods.

Relocation costs associated with interdiction were first described in NUREG/CR-3763 (Burke et al. 1984), where a recommended cost of $4,000 is provided for loss of personal and corporate income. This loss was based on a 100-day transition period to a new job or relocated existing job and a 180-day corporate relocation period. The $4,000 was scaled to the recommended value in (Sprung et al. 1990) of $5,000, where a range of $3,500 to $7,500 was also provided.

Escalation of this value from 1986 until 2015 using a factor of 2.14 would result in a value of $10,700 and a range of $7,490 to $16,090. Burke et al. (1984) did not include costs of moving belongings to new areas, explaining such costs should be small, since all tangible property in the interdicted area is assumed to be replaced. An alternate approach to lost income would be to use state-specific average incomes and average unemployment durations. Data from the BLS as reported by the St. Louis Federal Reserve Bank[25] indicates that although the annual average duration of unemployment from 1949 to 2000 ranged from 8-20 weeks, with an average value of 13 weeks, it has increased over the last decade, rising as high as 40 weeks in 2011 and 2012. This study uses a typical half-year (26-week) duration for unemployment insurance as the transition period. Data from the U.S. census[26] indicates a per-capita income from 2008 to 2012 of $23,906 to $25,309 for the two states within the EPZ. This results in an average value of lost income over a 6-month period of $12,303. Escalation from 2010 to 2015 using the BLS CPI calculator[27] factor of 1.08 results in a value of $13,287 per person. Considering the potential variation in length of unemployment (8-40 weeks) following displacement, this value could range from $4,000 to $20,000 per person. These values are slightly higher than, but reasonably consistent with, the values derived from escalation of the NUREG-1150 values in (Sprung et al. 1990).

However, because this analysis explicitly includes an intermediate phase, with lost income captured as a daily cost over the duration of the intermediate phase, SNL staff recommended that the analysis include lost income in the RELCST parameter and not include such a component in POPCST, instead recommending a value for POPCST based on moving costs alone. SNL staff found that moving expenses can be quite large for a typical household. The 2011 U.S. Transfer Volume and Cost Survey (Worldwide ERC 2011) provides the national average cost of relocation components. Summing the applicable components of the relocation costs (e.g., no bonus pay for the employee to move, no shipping of goods, etc.), relocation costs of about $20,000 appears reasonable. With 2.58 people per household, this corresponds to $7,750 per person. Escalation of this value from 2011 to 2015 using a Core CPI escalator of 1.077 yields a value of $8,344 per person (in 2015$), which is the value recommended for POPCST. This analysis uses this recommended value and considers the alternate derivation based on lost income to represent an alternative conceptual approach.

Estimation of Loss of Use Costs

The model for estimating compensation costs for loss of use of interdicted property divides economic costs into two groups, farm costs and nonfarm costs. Farm costs are calculated per hectare of farmland (worth of farmland and improvements per hectare, crop worth per hectare). Nonfarm costs are calculated per person (temporary and permanent relocation costs per

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25 http://research.stlouisfed.org/fred2/series/UEMPMEAN

26 http://quickfacts.census.gov/qfd/index.html#

27 http://www.bls.gov/data/inflation_calculator.htm

person, tangible worth of nonfarm property per person), where nonfarm property includes residential, commercial, public land, improvements, equipment, and possessions. The interdiction period is calculated by the MACCS code when it determines the necessary protective actions. For example, if decontamination alone is sufficient to restore habitability, the interdiction period is the duration of the decontamination period, as defined by TIMDEC. If decontamination is not sufficient, the interdiction period is the duration of the decontamination period plus the additional time during which property usage is prohibited.

The unit cost of compensation as a result of loss of usage of the property during the period of interdiction accounts for depreciation of the improvements to the land and for an expected rate of return on the entire property value for the duration of the interdiction period. For property that cannot be used during the emergency, intermediate, and a portion of the long-term phase, the period of interdiction includes this entire time period. The equation used to estimate the unit compensation cost for loss of use of nonfarm or farm property is

$$C_{loss\ of\ use} = V \cdot [(1 - F_{IM}) + F_{IM} \cdot \mathrm{e}^{-\mathrm{R_{DP}} \cdot \mathrm{T_{INT}}}] \cdot \mathrm{e}^{-\mathrm{R_{IR}} \cdot \mathrm{T_{INT}}}$$

where
V: unit value of wealth in the region (includes the cost of the land, buildings, infrastructure, and any nonrecoverable equipment or machinery ($/person or $/hectare), represented by the SecPop variables VNFRM and VFRM for nonfarm and farm wealth, respectively
F_{IM}: fraction of the wealth in the region resulting from improvements (unitless), represented by the MACCS variable FRNFIM or FRFIM, respectively
R_{DP}: depreciation rate, represented by the MACCS variable DPRATE
R_{IR}: inflation adjusted rate of investment return, represented by the MACCS variable DSRATE
T_{INT}: time period (s) for which the property is interdicted. For areas whose residents are relocated, this time period includes the durations of the emergency and intermediate phases, plus the period of decontamination and interdiction calculated by MACCS during the long-term phase

The values for the per-capita nonfarm wealth and per acre farm wealth are taken from the site file prepared by SecPop 4.3 (based on the SECPOP2000 model described in [Bixler et al. 2003]). As described in (Sprung et al. 1990) and in (Bixler et al. 2003), the values of V needed are the value of nonfarm property per person and of farm property per hectare (per acre).

The value of nonfarm wealth comes into MACCS in two ways. The site data input file contains a value of total nonfarm property value (VNFRM) for each economic region. VNFRM is used when MACCS estimates the cost associated with loss of use of property during interdiction and losses when land is condemned. VNFRM is estimated by SecPop from national and county-level economic data (as discussed in Section 3.4.2.1, the economic data in SecPop 4.3 is derived from a database with a base year of 2007 and was escalated to the project base year of 2015) and a value is included in the site file for each grid element. The CHRONC input file also requires a parameter, VALWNF, which is a single value that should characterize the area of interest and be representative of the VNFRM values. VALWNF is used in the decision process to determine whether it is economical to decontaminate land or whether it should be

condemned. The recommended value for VALWNF was obtained from the original site file developed using SecPop 4.2.2 by SNL staff and based on the area within 50 miles of the site and is $335,900 per person.

FRNFIM defines the fraction of nonfarm wealth in the region due to improvements. This value only applies to areas that are interdicted or condemned; therefore, the value only applies to areas that are estimated to have received significant contamination. A related parameter used to construct the economic database in SecPop is the fraction of property cost due to land value in the U.S. This value was reviewed and updated to be 0.45 with the 2007 revision of the economic database used by SecPop 4.3. To be consistent with this value, the value for the fraction of property value representing improvements used in this analysis is 0.55.

The value of farm wealth also comes into the MACCS model in two ways. The site data input file contains a value of total farm property value (VFRM) for each economic region. VFRM is used when MACCS estimates the cost associated with loss of use of property during interdiction and losses when land is condemned. VFRM is estimated by SecPop from county-level economic data and a value is included in the site file for each grid element. The CHRONC input file also requires a parameter, VALWF, that characterizes the entire analysis area, and this value should be representative of the VFRM values. VALWF is used in the decision process to determine whether it is economical to decontaminate land or whether it should be condemned. The value of VALWF used in this study was calculated to be the farm-area-weighted average of VFRM within 50 miles of the site. The recommended value for VALWF was obtained from SecPop 4.2.2 by SNL staff and is $8,415 per hectare.

FRFIM defines the fraction of farm wealth in the region due to improvements. The value includes farm buildings, nonrecoverable machinery, and any infrastructure such as silos or irrigation, which is devoted exclusively to the support of farming. According to the ERS (USDA), the farmland value represents 82 percent of the U.S. farm assets in 2012.[28] Therefore, the value due to improvements would be about 18 percent. The value for the fraction of farm wealth due to improvements used in this analysis was rounded to 20 percent.

DPRATE is defined as the depreciation rate that applies to property improvements during a period of interdiction (Jow et al. 1990). This depreciation rate is intended to account for the loss of value of buildings and other structures resulting from a lack of habitation and maintenance. In MACCS, the loss of value of buildings and other structures is assumed to depreciate based on a first-order model. The authors were unable to find any data on depreciation rates for untended property during a period of interdiction. As such, a value of 0.20 (or 20 percent per year) is taken from Appendix 6 of WASH-1400 (NRC 1975). This value was assumed by the authors of that earlier study to reflect the cost of property maintenance, but they go on to state that the depreciation rate is the "only parameter in the equation (for the present value of property following a period of interdiction) whose value could be seriously in error." Nonetheless, the

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[28] http://www.ers.usda.gov/topics/farm-economy/land-use,-land-value-tenure.aspx

value was judged to be appropriate because of a lack of maintenance during interdiction. When property is maintained, depreciation was usually judged to be in the range of 3 to 5%." Because a building that is not maintained would depreciate more quickly than a building that is maintained, the depreciation rate of 20 percent per year originally established in WASH-1400 remains reasonable. Table 5.1 of (Sprung et al. 1990) assigned a range of 10 percent to 30 percent per year. Table 1 of NUREG/CR-6134 (Helton et al. 1995a) assigned the value a uniform distribution with a range of 16 percent to 24 percent per year. However, neither of these references provided an explanation of how these distributions were determined.

DSRATE is defined as the expected rate of return from land, buildings, equipment, etc. Chanin et al. (1990). This parameter is intended to discount future years to the current year and to include the rate of return on debt and equity. Based on the initial definition of the parameter, which includes land and buildings, which are large contributors to this parameter, SNL staff recommended a value of 6 percent. This value, which considers GDP as well as corporate finance, is chosen as the base case for this analysis and is based on ongoing work to update protective action cost parameters (Jones, Bixler, and Kimura 2015). This value is subject to uncertainty. An alternate approach to quantifying DSRATE would be to use the recommended discount rate of 7 percent from the current revision of OMB Circular A-94, as this is described as approximating the marginal pretax rate of return on an average investment in the private sector in recent years.

3.4.2.5 *Decontamination Model*

As discussed in the previous section, the use of a habitability criteria in MACCS can result in land that is habitable only after decontamination. MACCS determines where decontamination may be required based on the computed level of contamination. During the decontamination period, the population from areas that are decontaminated is assumed to be relocated to uncontaminated areas. The decontamination plan data (and in particular, the cost of decontamination) is typically based on values from Sample Problem A, which appear to be escalated from the values in Section 4.4.5.1 in (Burke et al. 1984). However, (Burke,et al. 1984) relied on a review of decontamination effectiveness and costs which was identified as in preparation ("to be published"), but which cannot be located. The decontamination plan recommendations, based on ongoing SNL work to update the costs associated with protective actions, consider the contributions of costs from characterization, decontamination, waste management, transportation and disposal. A preliminary version of this work is documented in (Jones, Bixler, and Kimura 2015). Although this report remains under review, it provides a reasonably transparent basis for selection of decontamination plan parameters. Staff chose to use these values (escalated as appropriate) rather than escalating the values from Sample Problem A derived from (Burke et al. 1984), as the technical basis for those values are currently untraceable.

Decontamination Plan

The objective of decontamination is to reduce the projected dose below the long-term dose criterion. If the maximum decontamination level is insufficient to restore an area to immediate

habitability, a period of temporary interdiction following the maximum decontamination level is considered in order to allow for dose reduction through radioactive decay and weathering. If the property cannot be made habitable within 30 years (or if the farm property cannot be made farmable within 8 years), or if the cost of restoring habitability of the property exceeds the cost of condemning it, the property is condemned and considered to be permanently withdrawn from use (Chanin and Young 1998a). MACCS uses decontamination factors[29] (DFs) to represent the physical removal of radioactive material. The DF is the ratio of the initial and final surface contamination levels before and after the decontamination step (Jow et al. 1990). The decision process for implementation includes:

1. If no decontamination is required and the projected dose to the public is less than the habitability criterion, relocation or other mitigative actions are not required.
2. If decontamination using the lowest DF (i.e., DF = 3) reduces dose below the habitability criterion, the DF is applied, and residents are returned to the property after the time required to decontaminate (TIMDEC for DF = 3).
3. If decontamination using the next DF (i.e., DF = 5) reduces dose below the habitability criterion, the DF is applied, and residents are returned to the property after the time required to decontaminate (TIMDEC for DF = 5).
4. If decontamination using the highest DF (i.e., DF = 15) reduces dose below the habitability criterion, the DF is applied, and residents are returned to the property after the time required to decontaminate (TIMDEC for DF = 15).
5. If decontamination using the highest DF and interdiction for any time up to 30 years (8 years for farmland) results in a dose less than the habitability criterion, the DF is applied, and residents are returned to the property after the time required to decontaminate plus the additional interdiction time.
6. If either the habitability criterion cannot be attained within 30 years or the cost of decontamination and interdiction up to 30 years is greater than the cost of condemning the property, the property is condemned rather than decontaminated. The 30-year maximum duration for nonfarmland is hardwired in the code.

LVLDEC is the number of decontamination levels that can be used. MACCS allows three levels, each of which is intended to represent a decontamination strategy. Two levels have typically been applied in MACCS analyses. However, using two decontamination levels may provide an unintended level of conservatism in the estimation of decontamination costs because for any area where a low DF (say, DF = 3) is not sufficient, the model jumps to a much higher DF (say, DF = 15) which costs much more to implement, when only an incremental increase may have been necessary. For example, where MACCS may actually calculate the need for a DF of 3.1, the full cost per person is applied for implementing a DF of 15. Including an intermediate

[29] The MACCS user's manual uses the terms dose reduction factor and decontamination factor somewhat interchangeably, even though the concepts are different. Dose reduction factor is more general and allows for doses to be reduced by moving materials around to increase shielding (e.g., deep plowing). Decontamination means that contaminants are removed. The distinction can be important in terms of cost since decontamination necessarily involves disposal; whereas, dose reduction does not.

decontamination factor, like a DF of 5, would cost less to implement and represents a more realistic approach. The L3PRA project uses a value of 3 for LVLDEC.

DSRFCT defines the effectiveness for each decontamination level selected (Chanin and Young 1998a) and is described as the ratio of the initial and final surface contamination levels (Jow et al. 1990). It should be noted that this same formulation can also represent the use of dose-reduction techniques that reduce dose by measures other than removal of contamination. The effectiveness of the dose-reduction technique used to achieve a DF can be influenced by the type of contamination, timing of the decontamination activities, weather, the substrate being cleaned, and other factors. Sample Problem A applied decontamination levels of 66.7 percent (corresponding to a DF of 3) and 93.3 percent (corresponding to a DF of 15), while WASH-1400 applied a DF of 2 and a DF of 20 (NRC 1975). Each of these levels has an associated cost to implement, with a higher cost corresponding to the higher level of decontamination. In MACCS, if the lower level of decontamination is sufficient to restore habitability, it is selected, and the cost to perform the decontamination is tallied. If it is not sufficient to restore habitability, the next higher level of decontamination is applied, and its cost is tallied. Achieving a high decontamination factor often requires removal of surface materials (i.e., roofing, siding, etc.) or a two-phase approach, with an initial gross decontamination followed by a final decontamination. MACCS simulates both phases of a two-phase decontamination approach using a single DF. As recommended by (Jones, Bixler, and Kimura 2015), decontamination factors of 3, 5, and 15 are used in this analysis, corresponding to a cleanup efficiency of 66.7 percent, 80 percent, and 93 percent, respectively.

TIMDEC defines the time required for completion of each level of decontamination, beginning at the start of the long-term phase and continuing for the specified TIMDEC duration (Chanin and Young 1998a). The TIMDEC values must be monotonically increasing with the DF values. Limited data exists on duration of large-scale radiological decontamination, although ongoing activities in response to Fukushima enable useful insights to be drawn. Large-scale DOE site remediation activities also provide information, but these efforts were not typically schedule driven and so they have limited value in establishing decontamination times. The duration of decontamination activities may be influenced in part by the extent and location of the contamination, cleanup criteria, types of substrate contaminated, stakeholders, and the availability of resources. The lowest level DF represents cleanup of relatively lightly contaminated areas, typically requiring nondestructive techniques. In earlier analyses, decontamination times were lower for lower DF values, based on the assumption that lightly contaminated areas would be decontaminated first, followed by areas with increasingly higher levels of contamination. However, the dispersion of a plume is such that the largest land areas are likely to require the lowest level DF. Because this is the greatest area of land contamination, decontamination may possibly take longer than decontamination of areas where higher DFs are required. The parameter is also intended to reflect an average of the decontamination time for the farm and nonfarm land areas, which must be considered. Information from the Fukushima cleanup is becoming available as those decontamination efforts continue. Many decontamination activities at Fukushima have taken longer than the maximum duration allowed under MACCS. It can be seen from the Fukushima experience that a significant amount of time may also be needed after decontamination activities are completed before the occupancy

restrictions are lifted and the population returns. To account for the larger areas requiring a low DF and the MACCS constraint that lower DFs be equal or less in duration than higher DFs, all DFs are established at the same duration. The value selected is 1 year (365 days), which was the maximum value allowed in MACCS at the time the parameter values were developed.[30]

CDNFRM defines the nonfarmland decontamination costs for each level of decontamination. The MACCS User's Guide (Chanin and Young 1998a) and earlier documents (NRC 1975; Burke et al. 1984) discuss the approach to developing the cost value, but do not describe the cost elements of the decontamination process that were included. Decontamination costs in MACCS have typically been associated with cleanup of urban and semi-urban land use areas and are estimated on a per person basis. Decontamination costs were originally developed in WASH-1400 based on cleanup of streets, buildings, and homes, where characteristics typical of urban and rural lots were used in the analysis (NRC 1975). The decontamination costs are identified in WASH-1400; however, the details for converting these to cost per person are not provided. Similarly, in Table 4.4 of (Burke et al. 1984), the nonfarm decontamination costs per person are listed, but the source that is referenced to explain the per person allocation is unpublished. Using an inflation factor of 2.36 to escalate from 1983 until 2015, the original values for a DF of 3 ($2,600/person) and a DF of 15 ($6,900/person) in (Burke et al. 1984), would be approximately $6,300/person and $16,260/person, respectively, in 2015.

Based on ongoing work considering the contributions of costs from characterization, decontamination, waste management, transportation and disposal, (Jones, Bixler, and Kimura 2015) recommended values for CDNFRM for DFs of 3, 5, and 15 to be $7,600, $24,400, and 43,600, respectively, in 2014 dollars[31]. This approach includes contributing costs from characterization, decontamination, waste management, transportation, and disposal. An approach is also provided in that study to correlate population density with building density to allocate cost per person. The study provides definitions for different types of land use by developing general costs for low intensity (combined with developed open space), medium intensity, and high intensity land use. The population within each land use category was assumed to be 1 household on 10 acres for low intensity land use, 4 households per acre for

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[30] Although the most recent version of WinMACCS (3.11.2) allows decontamination times greater than 1 year, this version only became available shortly before completion of this analysis, and no work had yet been completed to develop a technical basis for an extended decontamination time. Staff, therefore, did not revise the input decks, and the analyses still use a 1-year decontamination period. Staff notes that current information (JMOE, 2018) suggests that the evacuation orders arising as a results of the accident at Fukushima were lifted for many of the municipalities in the Special Decontamination Area by March 2016, approximately 5 years after the accident. The document also states that "As a result, all planned "whole area decontamination" was completed in March 2018" (JMOE, 2018). With a 1-year intermediate period, this suggests that a 4-6 year decontamination period may be a reasonable alternative for sensitivity analysis given the information currently available from Fukushima.

[31] After development of the input decks for the L3PRA, an error was identified in the derivation of the values for CDNFRM in (Jones, Bixler, and Kimura, 2015). Preliminary evaluation suggest that this could lower the per-capita decontamination costs by a factor of less than 2 for DF3 and approximately 15 percent for DF5 and DF15. Because this report remains under review, an updated recommended value is not yet available. This is not expected to be a significant source of error in overall economic results reported in this project because decontamination costs are typically a small fraction of total economic costs in this analysis. Work is ongoing at the time of writing to further develop technical bases for this parameter.

medium intensity land use, and 10 households per acre for high intensity land use. Each household is assumed to have 2.58 persons, as discussed previously. The costs were then converted to represent a single average property for use in application of the MACCS parameters related to decontamination. Although farmland decontamination is considered separately, decontamination of uninhabited or otherwise undeveloped land was not considered, as this approach was based on a per-capita estimation. Staff review of this draft report suggests that the lower DF levels (e.g., a DF of 3) are based on relatively nondestructive techniques, such as debris and brush removal, pressure washing of exterior surfaces, and scrubbing of interior finishes, whereas the higher levels are associated with more invasive techniques, such as topsoil removal, road planning, and replacement of roofing shingles, siding, and interior finishes. These values could be a significant source of uncertainty in economic costs.

CDFRM defines the farmland decontamination costs for each level of decontamination. The MACCS User's Guide (Chanin and Young 1998a) and earlier documents (NRC 1975; Burke et al. 1984) discuss the approach to developing the cost value, but do not describe the actual cost elements of the decontamination process that are included in this value. WASH-1400 states that the cost of developing a disposal site is included in the unit cost, but does not provide sufficient information to evaluate its technical basis (NRC 1975). Furthermore, the unit costs are quite low, indicating that disposal was assumed to be very inexpensive or that it was not actually included. The original concept was to represent costs using a single farm decontamination cost value for each DF for a given site. The cost values can be adjusted, but guidance on adjusting the values was not provided. The NUREG-1150 values (Sprung et al. 1990) were developed for six sites, but the underlying assumptions for the different costs were traced to (Burke et al. 1984), which in turn referenced a document that cannot be located and may not have been published. Using an inflation factor of 2.36 to escalate from 1983 until 2015, the original values for a DF of 3 ($160/acre) and a DF of 15 ($440/acre) in (Burke et al. 1984), would be approximately $933/ha and $2566/ha, respectively, in 2015.

Based on ongoing work considering the contributions of costs from characterization, decontamination, waste management, transportation and disposal, (Jones, Bixler, and Kimura 2015) recommended values for CDFRM for DFs of 3, 5, and 15 to be $48,800,$65,300, and $83,100 per hectare, respectively[32]. Based on staff review of the draft report, these values are largely based on soil removal, and therefore are believed to be substantially larger than the values escalated from (Burke et al. 1984), due to the assumption of the cost of disposal of large volumes of lightly contaminated soil. Like the values for CDNFRM, these values are uncertain and are likely to be sensitive to assumptions made regarding the amount of waste disposal needed and the cost of waste disposal. It can be noted that with a VALWF value of $8415/ha, these parameters will most likely just condemn the farmland, if it is contaminated at any level exceeding habitability thresholds.

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[32] Work is ongoing at the time of writing to further develop technical bases for this parameter.

In summary, the decontamination plan used in the analysis (based on [Jones, Bixler, and Kimura 2015] and escalated from 2014 to 2015 using an escalator of 1.018) is provided in Table 3.4-21.

Table 3.4-21: Decontamination plan definition (2015$)

DECON LEVEL	DSRFCT	TIMDEC (days)	CDNFRM ($/person)	CDFRM ($/hectare)
1	3	365	7,739	48,800
2	5	365	24,846	65,300
3	15	365	44,397	83,100

Decontamination Worker Collective Dose Estimation

Decontamination workers engaged in the cleanup receive groundshine dose (Jow et al. 1990). To estimate the dose to decontamination workers, the following equation is used to estimate the total number of years workers spend in the contaminated area:

Worker Exposure Time = $(CDNFRM \times FRNFDL \times POPN \times TFWKNF) \div (DLBCST)$

Where:

CDNFRM = nonfarmland decontamination costs per person for each level of decontamination ($/person)
FRNFDL = fraction of the nonfarmland decontamination cost due to labor for each level of decontamination (dimensionless)
POPN = total population requiring a level of decontamination
TFWKNF = fraction of the decontamination period that a decontamination worker spends in the contaminated area for each DF
DLBCST = decontamination worker labor cost ($/worker-year)

Worker exposure time is expressed in worker-years. The worker exposure time is multiplied by an isotopic ground concentration and time-integrated, groundshine, dose-rate coefficient, summed over all isotopes, to get the total population dose for decontamination workers. The time integration is over the exposure period, $TIMDEC$. The result is a population dose expressed as worker-rem or person-rem. A similar equation is used for farmland, but is based on area rather than population, that is, $CDNFRM$ is replaced by $CDFRM$, which is in units of $/hectare, and $POPN$ is replaced by $AREAN$ in units of hectares. Two other parameters are replaced by their farm equivalent with the same units, that is, $FRFDL$ and $TFWKF$. Each of the parameters used in this equation is discussed below.

DLBCST is the labor cost of a decontamination worker in dollars per man-year (Chanin and Young 1998a). Jones, Bixler, and Kimura (2015) traced this parameter to the parameter DW (decontamination worker salary) in (Burke et al. 1984). The cost was estimated at $30,000 per man-year based on $10 per hour working a 56-hour work week (Burke et al. 1984). In May 2012, the median annual wage for hazardous material removal workers was $37,590, according

to the U.S. Bureau of Labor Statistics Occupational Outlook Handbook (DOL 2014). In 2015, the median salary was approximately $39,690.[33] Decommissioning and decontamination workers are included in this category. The work activities include removal and treatment of radioactive materials generated by nuclear facilities and power plants. Radiation protection technicians are also included in this category. The work activities include measuring, recording, and reporting radiation levels; operating high-pressure cleaning equipment for decontamination; and packaging radioactive materials for removal or storage. The 2015 unburdened cost therefore corresponds to $79,380, assuming a factor of 2 to cover overhead and all other non-direct labor costs.

FRFDL defines the fraction of farmland decontamination cost that is due to labor for each level of decontamination. This parameter was introduced in (Burke et al. 1984) as FL_f where values of 0.3, 0.35, and 0.35 were established for DFs of 3, 10, and 15, respectively. The study explains that the remainder of decontamination costs are based on building materials and cleanup equipment. An analysis of cost guidance and proposals provided a value of about 0.35[34] for current and similar work efforts. There is a difference in the number of work crews implementing the decontamination, but the fraction of cost from labor remains relatively constant and independent of the DF. The value of 0.35 recommended by (Jones, Bixler, and Kimura 2015) is used in this analysis for all farmland DFs.

FRNFDL defines the fraction of the nonfarmland decontamination cost that is due to labor for each level of decontamination. A value is needed for each decontamination level. This parameter was introduced in (Burke et al. 1984) as RL_f, where values of 0.3, 0.5, and 0.5 were established for DFs of 3, 10, and 15, respectively. As described above, there is a difference in the number of work crews implementing the decontamination, but the fraction of cost from labor is relatively constant and independent of the DF. The value of 0.35 recommended by (Jones, Bixler, and Kimura 2015) is used in this analysis for all nonfarmland DFs.

TFWKF defines the fraction of the decontamination period (TIMDEC) that a farmland decontamination worker spends in the contaminated area and must be provided for each DF value used in the analysis (Chanin and Young 1998a). This parameter is used to estimate the dose to decontamination workers. The origin of the parameter was not identified in this research. However, (Burke et al. 1984) identified a dose-reduction parameter for farm and nonfarm decontamination workers. The dose-reduction parameter was described as appropriate because farm decontamination workers were likely using heavy equipment, possibly graders or loaders that sit well above the contaminated ground and are heavily shielded vehicles (Burke et al. 1984); whereas, decontamination of urban areas often requires closer contact with the contaminated substrate using portable equipment such as scrubbers, scabblers, vacuums, etc. The current MACCS model does not include a dose-reduction factor for decontamination workers. Based on decontamination experience and discussions with decontamination

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[33] https://www.bls.gov/ooh/construction-and-extraction/hazardous-materials-removal-workers.htm

[34] Information provided by Environmental Dimensions, Inc., as documented in (Jones, Bixler, and Kimura, 2015).

contractors,[35] it is estimated that only 35 percent of the decontamination effort is labor within the contaminated area. The remaining labor occurs outside of contaminated zones. The fraction of time this labor spends in the contaminated area was estimated by SNL staff as 10 percent. The makeup of the crews is assumed not to differ based on the level of contamination; therefore, the fraction of the decontamination period that a farmland decontamination worker spends in the contaminated area is the same for each DF level used in the analysis. The value recommended by SNL staff of 0.10 is used in this analysis.

TFWKNF defines the fraction of the decontamination period (TIMDEC) that a nonfarmland decontamination worker spends in the contaminated area for each DF value used in the analysis. This parameter is used to capture the dose to the decontamination workers. The only difference from TFWKF described above is that this parameter applies to nonfarmland. The decontamination of nonfarmland would typically include smaller equipment, often hand held, and the workers are operating in closer proximity to the contaminated substrate, not shielded by heavy equipment. However, the shielding from the equipment is not factored into the TFWKF parameter. The remaining assumptions related to time in the decontamination area are the same; therefore, the value recommended by SNL staff of 0.10 is used in this analysis.

3.4.3 MACCS Protective Action/Economic Cost Input Parameter Summary

A summary of the MACCS input parameters related to protective action parameters, site data, and economic factors is provided in Table 3.4-22.

Table 3.4-22: Summary of MACCS input parameters related to protective action parameters, site data, and economic factors

Variable	Description	Value	Source
ENDAT2	Control flag indicating only ATMOS and EARLY are to be run	.FALSE.	
WTNAME	Type of Weighting for Cohorts	SUMPOP	Sect. 3.4.2.1
POPFLG	Population Distribution Flag	FILE	
Site File	Name of Site File	Table 3.4-5	
NUM_EVAC_SCEN	Number of cohorts	18	
NUMFIN	Number of Fine Grid Subdivisions for Early-Phase Dose Projections	7	Sect. 3.4.2.2
ENDEMP	Emergency-phase duration	10 days	
DUR_INTPHAS	Intermediate-phase duration	Table 3.4-13	
EXPTIM	Late-phase exposure duration	50 years	
CSFACT (General Public)	Cloudshine shielding factor for general public cohorts	0.75/0.6/0.95 (NORM/SHLT/EVAC)	
CSFACT (Schools/Industrial)	Cloudshine shielding factor for schools and industrial worker cohorts	0.31/0.31/0.95 (NORM/SHLT/EVAC)	

[35] SNL staff (Jones, Bixler, and Kimura, 2015) consulted with Environmental Dimensions, Inc., who have direct and current experience in commercial decontamination projects.

Variable	Description	Value	Source
PROTIN (General Public)	Inhalation protection factor for general public cohorts	Median from Table 3.4-7	
PROTIN (Schools/Industrial)	Inhalation protection factor for schools and industrial worker cohorts	0.33/0.33/0.98 (NORM/SHLT/EVAC)	
SKPFAC (General Public)	Skin protection factor for general public cohorts	Median from Table 3.4-7	
SKPFAC (Schools/Industrial)	Skin protection factor for schools and industrial worker cohorts	0.33/0.33/0.98 (NORM/SHLT/EVAC)	

Table 3.4-22: Summary of MACCS input parameters related to protective action parameters, site data, and economic factors (continued)

Variable	Description	Value	Source
GSHFAC (General Public)	Groundshine shielding factor for general public cohorts	Median from Table 3.4-6	Sect. 3.4.2.2
GSHFAC (Schools/Industrial)	Groundshine shielding factor for schools and industrial worker cohorts	0.1/0.1/0.4 (NORM/SHLT/EVAC)	
LPROTIN	Chronic inhalation protection factor	1	
LGSHFAC	Chronic groundshine shielding factor	0.22	
BRRATE	EARLY breathing rate	0.000219 m^3/s	
LBRRATE	CHRONC breathing rate	0.000219 m^3/s	
NGWTRM	Number of terms in groundshine weathering equation	2	
GWCOEF	CHRONC groundshine factors	0.5, 0.5	
TGWHLF	CHRONC groundshine half-lives (s)	1.6E7; 2.8E9	
RESCON	EARLY resuspension factor	Table 3.4-9	
RESHAF	EARLY resuspension half-life	Table 3.4-9	
NRWTRM	CHRONC number of resuspension weathering terms	3	
RWCOEF	CHRONC resuspension factors	Table 3.4-9	
TRWHLF	CHRONC resuspension half-lives	Table 3.4-9	
FDPATH	COMIDA2 versus MACCS Food Model Switch	NEW	
COMIDA File	Name of COMIDA file	comida2_FGR13GyEquivDCF.bin	
DOSEMILK	Max milk dose first year	0.0375 rem effective 0.375 rem thyroid	
DOSEOTHER	Max food dose first year	0.14 rem effective 1.4 rem thyroid	
DOSELONG	Max food dose subsequent years	0.14 rem effective 1.4 rem thyroid	
NUMWPI	Number of water ingestion radionuclides	4	
NAMWPI	Water ingestion radionuclides	Sr89, Sr90, Cs134, Cs137	
WSHFRI	Initial washoff fraction	0.01, 0.01, 0.005, 0.005	
WSHRTA	Annual washoff rate	0.004, 0.004, 0.001, 0.001	
KIMODL	Model flag for KI ingestion	NOKI	
EVATYP	Radial or network model flag	NETWORK	

Variable	Description	Value	Source
KEYAVAIL	Flag indicating availability of keyhole model	KEY_AVAIL	Sect. 3.4.2.3
EVAKEY	Evacuation algorithm	Table 3.4-15	
KEYFORCST	Hours of forecast weather available	3	
NSECTR	Number of sectors in keyhole	13	
KEYDIS	Number of rings in circular area of keyhole	9	
TRAVELPNT	Flag used to define the location of an evacuee	CENTERPOINT	

Table 3.4-22: Summary of MACCS input parameters related to protective action parameters, site data, and economic factors (continued)

Variable	Description	Value	Source
NUMEVA	Number of radial elements comprising the sheltering and evacuation region	25	Sect. 3.4.2.3
LASMOV	Outermost spatial interval of the evacuation movement zone	28	
REFPNT	Reference time point for evacuation zone	ALARM	
OALARM	Time after accident that offsite alarm is initiated (s)	0 (included in DLTSHL)	
DLTSHL	Delay to shelter	Table 3.4-17	
DLTEVA	Delay to evacuation	Table 3.4-15	
DURBEG	Duration of the initial evacuation phase	Table 3.4-15	
DURMID	Duration of the middle evacuation phase	Table 3.4-15	
ESPEED	Travel speed of evacuees	Table 3.4-15	
ESPMUL	Speed multiplier during adverse weather	0.85	
ESPGRD_NET	Grid-dependent speed multiplier	Table A.3	
IDIREC	Evacuation direction	Table A.4	
CRIORG	Critical organ for EARLY relocation	L-ICRP60ED	Sect. 3.4.2.4
DOSHOT	Hotspot relocation dose threshold	5 rem	
DOSNRM	Normal relocation dose threshold	1 rem	
TIMHOT	Hotspot relocation action time	Table 3.4-21	
TIMNRM	Normal relocation action time	Table 3.4-21	
DPPEMP	Dose projection period for the emergency phase (s)	3.46E5 (4 days)	
CRTOCR	Critical organ for intermediate-phase relocation and late-phase interdiction	L-ICRP60ED	
DSCRTI	Intermediate-phase dose criterion	2 rem	
DPP_INTPHAS	Dose projection period for the intermediate phase (s)	3.15E7 (1 year)	
DSCRLT	Late-phase dose criterion	0.5 rem	
TMPACT	Late-phase dose projection period (s)	3.15E7 (1 year)	
EVACST	Daily compensation for evacuees and relocatees	$190	
RELCST	Daily compensation for intermediate-phase relocatees	$135	
POPCST	Per-capita removal cost for long-term interdiction	$8,344	

Variable	Description	Value	Source
DPRATE	Depreciation rate for improvements	20%	
DSRATE	Rate of return on investment for property; discount rate for estimating current worth	6%	
VALWF	Farmland wealth per hectare	$8,415/hectare	
FRFIM	Farmland wealth improvements fraction	0.2	
VALWNF	Nonfarm wealth per person	$335,900/person	
FRNFIM	Nonfarm wealth improvements fraction	0.55	
LVLDEC**	Number of decontamination levels	3	Sect. 3.4.2.5
TIMDEC	Decontamination time	1 yr	
DSRFCT	Decontamination efficiency	3, 5, or 15	

Table 3.4-22: Summary of MACCS input parameters related to protective action parameters, site data, and economic factors (continued)

Variable	Description	Value	Source
CDFRM**	Decontamination cost, farmland	Table 3.4-22	Sect. 3.4.2.5
CDNFRM**	Decontamination cost, nonfarm	Table 3.4-22	
DLBCST	Decon labor cost	$79,380/year	
FRFDL	Labor decon cost fraction, farmland	0.35	
FRNFDL	Labor decon cost fraction, nonfarm	0.35	
TFWKF	Labor decon time fraction, farmland	0.1	
TNFWKF	Labor decon time fraction, nonfarm	0.1	

Note: decon.: decontamination

**Not applicable when using SUMPOP.*

*** Work is ongoing at the time of writing to further develop technical bases for this parameter.*

3.4.4 Identification and Discussion of Uncertainties Related to Protective Actions Parameters, Site Data, and Economic Factors

There are a numbers of sources of uncertainty in the calculation. These are listed in Table 3.4-24 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.4-25 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.4-24. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS.

The significance of sources of uncertainty in site data and protective actions is expected to be a function of the characteristics of the source term being analyzed. Most of the source terms in the L3PRA project are relatively delayed, such that protective actions effectively limit (or completely eliminate) doses in the early phase. For these source terms, exposures therefore tend to be dominated by long-term exposure to lightly contaminated areas after reoccupation. The significant sources of uncertainty are therefore expected to be those associated with the long-term exposure pathways. Since these doses are predominantly associated with groundshine, and the shielding factor is a linear multiplier on the groundshine dose, this shielding factor is expected to be a significant source of uncertainty. For the earlier release sequences in which protective actions may not be as effective in eliminating early exposures,

shielding factors related to plume exposure, particularly the inhalation protection factor PROTIN, could become a significant contributor to uncertainty.

Likewise, evacuation delays (DLTSHL, DLTEVA) and speeds (ESPEED) could be a significant source of uncertainty for some release categories. KEYFORCST is similar to an evacuation delay in that it limits the onset of evacuation until a specified time before the wind is projected to shift. For these parameters, the significance of the uncertainty is believed to be a function of the timing of the release. Many of the releases modeled in the L3PRA project have a sufficiently long warning time that the results may be relatively insensitive to even relatively large changes in the evacuation timing of the cohorts within 10 miles. The significance of the uncertainty in the evacuation parameters would increase to the extent that the releases overlap with the clearance of the evacuation zone. This effect would be most pronounced for early releases, such as bypass events. For intermediate and late containment failure sequences, which typically have a much longer warning time, the significance of uncertainties in evacuation parameters is expected to be much lower. In this analysis, hotspot and normal relocation times are not expected to be as significant for many sequences, since evacuation is explicitly modeled out to a distance of up to 20 miles and doses are projected to be low (under PAG limits) beyond this distance. For some of the largest releases, under which PAG projections could be exceeded beyond 20 miles, hotspot and normal relocation times could be significant, because these populations are modeled as non-evacuating and therefore subject only to early-phase relocation. This effect can be seen in Tables 6-13 through 6-15 of (SNL 2019), where relocation times are not a significant contributor to uncertainty within the 10-mile evacuation zone, but are significant beyond the evacuation zone.

The suite of cost parameters all have the potential to be significant sources of uncertainty in the estimation of economic impacts. Because MACCS also includes consideration of economic costs in long-term cleanup decisions (i.e., actions which would result in economic impacts greater than the value of the property being decontaminated will result in permanent interdiction rather than decontamination and reoccupation), very high projected recovery costs can also impact estimates of doses and health risks from long-term exposure. Because the total economic impact is comprised of a number of different cost categories, the overall results may not be highly sensitive to any single cost parameter. However, the lack of empirical data on the costs of recovery from a large-scale radiological incident suggests that there could be large uncertainties in economic costs. These costs are difficult to extrapolate from the limited real-world data from Chernobyl and Fukushima, due to the potential differences in recovery strategies and compensation structures that would be put in place in different countries. The use of input-output models, which are used to estimate the impact of disruptions to different sectors of an economy, may be a more suitable method for assessing economic impacts (at least in relation to impacts on GDP). Parameters that affect multiple cost categories are expected to demonstrate more model sensitivity and, therefore, would be expected to be more important contributors to uncertainty. Examples include the habitability criteria (DSCRLT and TMPACT), which would increase or decrease the extent of protective actions, and the length of the intermediate or recovery phases (DUR_INTPHAS and TIMDEC).

Table 3.4-23: Uncertainties related to protective action parameters, site data, and economic factors

PA/EC 3.4.2.1 Site Demographic Characteristics	The exposure models do not account for diurnal (i.e., work-related), seasonal (i.e., recreational uses, farm workers) or longer term (i.e. construction workforces) transient populations. This could be a significant source of uncertainty for transient populations near the site, but since these are not expected to be large populations, this is not expected to be significant for most reported consequence measures. However, early health effects could be highly sensitive to changes in the actual population distribution within a few miles of the site.
	There will be a variability in individual responses that is not captured in a discrete number of homogenous cohorts. However, with the relatively large number of cohorts modeled in the L3PRA project, including the discretization of the general public into four timing cohorts over three spatial intervals, it is expected that the variability is likely to be captured and this is not expected to be a significant source of uncertainty.
	There will be changes in the distribution of population over the period of interest (i.e., immigration, emigration, births, deaths, etc.). that are not captured by a single population distribution. Some collective consequences, such as total health effects cases, population dose, economic impacts, etc., are relatively linear with respect to total population. This could be investigated with sensitivity analyses based on alternate site files, with different estimates for population growth, by selecting an alternate base year for the analysis.
PA/EC 3.4.2.2 Characterization of Exposure Pathways	Exposure parameters (i.e., breathing rates, fraction of time indoors/outdoors, crop consumption rates, etc.) do not explicitly account for variability within the exposed population. Information on the variability in important exposure parameters is available in the EPA Exposure Factors Handbook (EPA 2011). This is not expected to be a significant source of uncertainty except for late evacuees during very early releases, where there is the potential for exposure to the passing plume.
	Shielding factors are a function of the roughness of the surface on which the material is deposited, building type, location of deposited material (e.g., roof versus ground), location within structure, spectrum of emitted radiation, topography/land use, etc. These are all represented by single shielding factors. The effect of these factors is discussed in NUREG/CR-6526. The effect of variability in shielding factors was examined in the SOARCA uncertainty analyses (SNL 2016, 2019). Shielding factors are expected to be a significant source of uncertainty.
	The location of the individual, which affects the shielding afforded by structures, is a function of the behavior of the individual. For example, whether the individual is an agricultural or outdoor worker, an indoor worker, a nonactive adult, a child, etc., will affect how much time they spend in different locations, each of which would have its own shielding characteristics. The effect of these factors is discussed in NUREG/CR-6526. The effect of occupancy patterns (i.e., time spent in different locations) on shielding factors could be a significant source of uncertainty.

Table 3.4-23: Uncertainties related to protective action parameters, site data, and economic factors (continued)

PA/EC 3.4.2.2 Characterization of Exposure Pathways	The transfer of deposited material from the exterior to the interior of structures is subject to uncertainty. The efficiency of air exchange by ventilation systems, or by open or damaged windows or doors, will affect the ratio of outdoor to indoor air concentrations. Deposited material may also be transported indoors by foot traffic. The effect of these factors is discussed in NUREG/CR-6526. The effect of air exchange on shielding factors could be a source of uncertainty.
	Weathering and resuspension factors are based on empirical models derived from limited datasets, the applicability of which to the site is uncertain. In addition, the rate at which material weathers can depend strongly on the type of initial deposition (i.e., material deposited by wet deposition may be more strongly bound than material deposited by dry deposition) and the type of surface on which the deposition occurs. For example, material deposited on roadways may be rapidly weathered by vehicular traffic, and material deposited on roofs may be washed off by rainfall following deposition; however, material deposited by dry deposition on walls may be removed quite slowly. The same factors will affect the degree to which deposited material can be resuspended and inhaled. The effect of these factors is discussed in NUREG/CR-6526.
	The estimation of location-specific individual exposure from ingestion (food, water, soil, etc.) is subject to uncertainty, particularly since food and water may be distributed away from the point of initial deposition.
	Parameters used for modeling food-chain transport are subject to uncertainty. Some of the parameters selected for elicitation in NUREG/CR-6523 include the rate at which deposited material migrates into soil, the rate at which the radioisotopes are fixed and unavailable for plant uptake, the fraction of deposited material that is taken into the plant via root uptake or foliar deposition, and the rate at which deposited material is resuspended onto plant surfaces by precipitation. Information on the uncertainty in these variables is provided in NUREG/CR-6136, NUREG/CR-6523, and Chapter 6 of (Bixler et al. 2013). This could be a significant source of uncertainty for collective effects.
	Although computed results show that collectives doses from ingestion of surface water contaminated by deposition can be a noticeable contributor to overall population dose (on the order of 10 percent), the surface water ingestion model is highly simplified and the parameters are subject to uncertainty. The significance of this is uncertain but is believed to be low in relation to the uncertainties in food-chain modeling, because water quality is easily monitored.
	The start and duration of protective action phases (i.e., early, intermediate, and recovery) are approximate and may overlap or occur at slightly different times at different locations. This is not expected to be a significant source of uncertainty.

Table 3.4-23: Uncertainties related to protective action parameters, site data, and economic factors (continued)

PA/EC 3.4.2.2 Characterization of Exposure Pathways	The extent of agricultural interdiction following an accident is uncertain. A more stringent precautionary interdiction would lead to lower collective doses from food, but higher economic impacts from the loss of crop sales. This could be a significant source of uncertainty on both doses and costs, albeit in an offsetting fashion.
PA/EC 3.4.2.3 Evacuation, Sheltering, and KI Administration	The timing of protective action recommendations, particularly recommendations for protective actions beyond the EPZ, are subject to uncertainty. The effect of different timings has been addressed in previous studies. This uncertainty may be subject to a cliff-edge effect, in that the timing is important to the extent that it affects whether the evacuation area is cleared prior to plume arrival. If the uncertainty in the timing does not result in exposure to the plume, then the effect may be insignificant. However, if the warning time is insufficient to allow clearance of the evacuation area, then doses from plume passage (cloudshine and cloud inhalation) to evacuating cohorts could be significant. Site-specific assessments of the uncertainty in evacuation times and speeds was conducted as part of the in the SOARCA uncertainty analyses (SNL 2016, 2019).
	The fraction of the population that does not evacuate when ordered is unknown. Experience has shown that although the majority of individuals will comply with evacuation orders, a small fraction of individuals may fail to evacuate. Information available in NUREG/CR-6864 (Identification and Analysis of Factors Affecting Emergency Evacuations) contains some information on the potential extent of non-evacuation, but much of the information is qualitative. This is not expected to be a significant source of uncertainty for population-dependent results within 20 miles because this population is expected to be a small fraction of the overall population within the evacuation zone.
	Although the effectiveness of KI is subject to uncertainty, it is not considered to contribute to the uncertainty in this analysis as it is not planned for use at this particular location.
	The magnitude and timing of shadow evacuation is subject to uncertainty. Shadow evacuation may reduce doses to those who are modeled as evacuating, but could result in traffic congestion that could reduce evacuee travels speeds. This could lead to increased doses for the evacuee cohorts, but only if the effect resulted in evacuations that were incomplete before plume arrival.
	The effect of adverse weather, particularly rare or extreme events such as ice storms, high winds, etc., on protective actions is subject to uncertainty. Severe weather could affect both evacuee speed estimates because of degraded road conditions and increase the amount of time needed for notification and mobilization because of the potential loss of power or damage to notification systems. Also, to the extent that severe weather is correlated to the initiating event, there may be dependencies between the Level 1/2/3 portions of the model.

Table 3.4-23: Uncertainties related to protective action parameters, site data, and economic factors (continued)

PA/EC 3.4.2.3 Evacuation, Sheltering, and KI Administration	The daily cost associated with short-term relocation (i.e., EVACST) is uncertain. The current model is based on per-diem rates in large cities and does not explicitly quantify the potential for the cost either of group shelters or of accommodation provided by private individuals (i.e., staying with family or friends outside the evacuation area). The significance of the early-phase aspect of relocation is not expected to be high, but the daily costs of relocation for longer periods could prove to be a significant source of uncertainty in economic estimates.
	Uncertainties in the traffic models used for evacuation time estimates will propagate forward into the evacuation model used in this analysis.
	Estimates for relocation times are uncertain, as the amount of time needed to identify, notify, and mobilize populations outside of the EPZ can be difficult to assess. Longer relocation times can increase radiological doses when groundshine is a significant contributor to dose, which is typically the case. Site-specific assessments of the effect of this were conducted as part of the in the SOARCA uncertainty analyses (SNL 2016, 2019). This is not expected to be a significant source of uncertainty because for most release categories, evacuation has been explicitly modeled for areas where PAGs are expected to be exceeded. This could be a significant source of uncertainty for large releases with the potential for extensive early-phase relocation beyond the 20-mile evacuation zone.
PA/EC 3.4.2.4 Relocation and Interdiction Models	Long-term cleanup levels are uncertain, as decisions on cleanup would be made following the accident with interaction from multiple stakeholders. This effect was shown to be significant in NUREG/CR-6134 (Helton et al. 1995a). The effect of varying the habitability criteria has been examined in multiple studies (e.g., [Mubayi et al. 1995]), demonstrating that there is a tradeoff between doses/health impacts and economic impacts (i.e., more stringent long-term levels reduce doses, but increase the extent of protective actions needed, thereby increasing costs). This could be a significant source of uncertainty on both doses and costs, albeit in an offsetting fashion.
	Alternate conceptual approaches exist for quantifying the economic impact of interdiction of land following an accident. The current approach in MACCS, referred to as a cost-based model, computes losses from depreciation and loss of use of property. Alternate approaches, such as input-output models, can be used to estimate the impact of disruptions of economic sectors. The significance of this is uncertain and could be examined with the use of a model that is based on input-output modeling.
	The economic impact of relocation and interdiction is uncertain. In particular, the values used to evaluate the depreciation (DPRATE) and the loss of use of interdicted property (DSRATE) are challenging to quantify. Lower depreciation and lower returns would reduce economic impacts, whereas higher depreciation and projected returns would increase the impacts. This could be a significant source of uncertainty in economic impacts.

Table 3.4-23: Uncertainties related to protective action parameters, site data, and economic factors (continued)

PA/EC 3.4.2.4 Relocation and Interdiction Models	The length of the intermediate phase is uncertain. This affects both dose and cost, because weathering and radioactive decay can result in a significant drop in the dose rate over a period of months, but the costs of intermediate-phase relocation would rise approximately linearly with the duration of the intermediate phase. However, increasing the intermediate phase may lower the amount of land requiring decontamination, thereby partially offsetting the impact of a longer intermediate phase. The significance of this is uncertain. The effect of this could be examined with sensitivity analysis on the variable DUR_INTPHAS.
PA/EC 3.4.2.5 Decontamination Plan	Estimates of the costs of decontamination, particularly of the decontamination time and costs, are subject to uncertainty. As discussed in the text, commonly used values of per-capita and per-hectare costs from Sample Problem A are traceable to a reference in (Burke et al. 1984) that does not appear to have been published. The values in the L3PRA analysis are based on ongoing work to update those values. This could be a significant source of uncertainty, but it should be noted that other cost components (e.g., intermediate-phase costs and loss-of-use costs associated with interdiction) may be comparable to, or larger than, the decontamination cost component.
	The time needed to complete decontamination and re-establish occupancy is subject to considerable uncertainty. This is likely to be a significant source of uncertainty in total economic costs, as costs associated with loss of use of the land would accumulate with time.

Table 3.4-24: Potential sensitivity analyses to address uncertainties in protective action parameters, site data, and economic factors

Analysis	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
PA_1	Increased relocation times	Relocation times (TIMHOT, TIMNRM)	Increased early-phase doses to non-evacuating cohorts; limited effect overall due to dominance of CHRONC results	Cyclic file set
PA_2	Examine uncertainty introduced by evacuation times	Reduced evacuation speeds (ESPEED) and increased evacuation delay (DLTEVA)	Potential increase in early-phase doses to late evacuating cohorts; limited effect overall due to dominance of CHRONC results	Cyclic file set
PA_3	Elimination of schools cohort to examine uncertainties introduced by assumptions about dismissal of schools at SAE to serve as shelters	Population files with no population assigned to schools cohorts	Negligible effects overall; slight increase in collective and population-weighted risks due to larger population in 10-15 mile region	Alternate input decks
PA_4	Examine uncertainty associated with shielding factors	GSHFAC/LGSHFAC, CSFACT, PROTIN/LPROTIN,SKPFAC sampled from distributions in Tables 3.4-6 and 3.4-7	Doses expected to be proportional to shielding factors	WinMACCS sampling
PA_5	Examine uncertainty associated with breathing rate	BRRATE/LBRRATE sampled from distributions in Table 3.4-8	Doses expected to linearly increase with breathing rate for cohorts exposed during plume passage	WinMACCS sampling

Table 3.4-24: Potential sensitivity analyses to address uncertainties in protective action parameters, site data, and economic factors (continued)

Analysis	Objective	MACCS parameters to be varied	Expected Results	Implementation Method
EC_1	Examine influence of phase durations on dose and cost results	Phase durations (DUR_INTPHAS, TIMDEC) set to range of values	Reduced phase durations hypothesized to reduce costs. However, reductions in intermediate-phase duration may result in more land subject to decontamination, so net effect is uncertain.	Cyclic file set
EC_2	Examine influence of assumptions about return criteria on dose and cost results	DSCRLT	Population doses and costs expected to be proportional/inversely proportional to habitability criteria	Cyclic file set
EC_3	Examine influence of decontamination plan (levels and unit costs) on dose and cost results	CDFRM, CDNFRM, DSRFCT	Increased unit costs expected to increase economic impacts. Very high unit costs may result in increased condemnation of farmland and non-farmland, resulting in higher costs but lower doses	Cyclic file set

3.5 Dosimetry (DO)

3.5.1 Assumptions and Known Limitations

- The assumptions and limitations of the MACCS code apply (i.e., only one chemical form for each nuclide, etc.). These are discussed in more detail in the text.
- The list of organs that can be used is hardwired within the version of the MACCS code used to develop the input decks. Organs not included on this list, even though present in the DCF files, cannot currently be used in MACCS calculations. Due to a limitation of eight lifetime dose coefficients representing specific organs (excluding the effective pseudo-organ, L-ICRP60ED) that are read from the DCF file, MACCS calculates the dose to seven specific cancer sites and one residual cancer site.
- To estimate residual cancers, the dose coefficients for the pancreas are used as a surrogate for dose to soft tissue. Because MACCS does not currently read the data for the pancreas from the dose coefficient file, values of the dose coefficients for the pancreas were copied into the organ called bladder wall. Thus, residual cancers are associated with the organ called bladder wall, which actually contains dose coefficients for the pancreas.
- Dose coefficients are based on the most recent update released for the Federal Guidance Report (FGR), which is currently FGR-13 (EPA 1999).
- The use of age and gender average dose coefficients for all cohorts, including special facilities such as schools or industrial facility workers, is assumed to reasonably reflect average characteristics of the populations in those cohorts.
- The inhalation coefficients for aerosols assume an activity median aerodynamic diameter of 1 µm, a geometric standard deviation of 2.5, a density of 3 g/cm3, and a shape factor of 1.5.
- The lung absorption types for aerosols are consistent with (Runkle and Ostmeyer 1985) for severe accidents at light water reactors. The lung absorption type for a specific radionuclide may be viewed by opening the DCF file and reading the corresponding value in lines 32 through 856.
- FGR-13 assigned f1 values for ingestion based on the form expected to persist in the environment, and these values are not necessarily consistent with the f1 values used in the computation of inhalation dose coefficients.

3.5.2 Technical Discussion

The dosimetric quantities computed by MACCS for use in modeling protective action decisionmaking or health effects are based on a dose coefficient approach. In general, the radiological dose to a receptor in a given spatial element is the product of the following quantities:

$$D_{i,j} = C_i \cdot ED_j \cdot UF_j \cdot SF_j \cdot DCF_{i,j}$$

Where

$D_{i,j}$	Dose to an organ or whole body from a radionuclide i and exposure pathway j
C_i	Integrated air concentration (Bq-s/m^3) or total ground deposition (Bq/m^2) of radionuclide i

ED_j	Exposure duration for exposure pathway j
UF_j	Usage factor where applicable (e.g., breathing rate for inhalation), for exposure pathway j
SF_j	Shielding factor for exposure pathway j
$DCF_{i,j}$	Dose coefficient for radionuclide i and pathway j

When exposure periods are long compared with radioactive decay rates or rates of weathering that effectively reduce the shielding factors, the time interval, ED_j, in the above equation is replaced by an integral over time. The total dose to an organ used for modeling of health effects, or to the whole body for modeling protective action decisionmaking, is then given by

$$D_{Total} = \sum_i \sum_j D_{i,j}$$

The total dose to the whole body is not calculated by summing the dose from all organs, such as is done when summing total cancers. Rather, an effective dose is calculated with a dose coefficient that represents the whole body. This effective dose is used for certain protective action thresholds, as well as for computing a collective population dose.

The detailed model formulation for each exposure pathway is discussed in Chapter 3 of (Jow et al. 1990). Two kinds of doses, corresponding to the two types of health effects considered in MACCS, are calculated: (1) acute doses arising from exposures during the early phase, used for calculating early fatalities and injuries, and (2) lifetime doses from all phases of the accident, used for calculating cancers. Lifetime doses are calculated by adding the total dose assigned to the early phase (i.e., early external doses and committed doses from early-phase intake) to the chronic doses in the late phase for the relevant exposure pathways. The exposure pathways considered during the emergency phase include cloudshine, groundshine, cloud inhalation, and inhalation of resuspended radionuclides. The exposure pathways considered during the intermediate phase include groundshine and inhalation of resuspended radionuclides. The exposure pathways for the long-term phase include groundshine, inhalation of resuspended radionuclides, food ingestion, and water ingestion.

The quantities used in the dose equations depend on the exposure pathway and are either user inputs or are computed internally by MACCS.

- The radionuclide concentrations are calculated by the ATMOS module at ground level along the plume centerline. In order to calculate the doses at different locations within a spatial element, a correction factor (discussed in Sections 3.1.1 and 3.2.1 of [Jow et al. 1990]) is derived to estimate the average air or ground concentration in a spatial element based on the Gaussian profile, the number of spatial elements, and the distance from the plume centerlines. These correction factors are internal to the MACCS code, as discussed in Section 3.4.2.2.

- The duration of exposure depends on the exposure pathway and the protective actions at a spatial element, and is either calculated by MACCS or supplied by the user, as discussed in Section 3.4.2.2.
- The shielding factor is a dimensionless quantity used to reduce the radiation dose as a result of shielding protection provided by a given protective action for a given exposure pathway. It is supplied by the user, as discussed in Section 3.4.2.2.
- Breathing rates for inhalation pathways are supplied by the user, as discussed in Section 3.4.2.2.
- Transfer coefficients for resuspension inhalation and ingestion pathways are supplied by the user, as discussed in Section 3.4.2.2.
- The dose coefficients for all exposure pathways and exposure types (acute and lifetime) are provided by the MACCS dose coefficient file.

Dosimetry and health effects modeling for the original MACCS code was based on data from the NUREG/CR-4214 series of radiation health effects reports (Evans et al. 1985, as updated). The results of these studies were implemented in the DOSFAC2 methodology (Young and Chanin 1997). In 1998, the dose coefficients from Federal Guidance Reports 11 and 12 (FGR-11, FGR-12) were implemented in the FGRDCF methodology (Chanin and Young 1998b). However, the FGRDCF methodology was limited in that the information needed for computation of acute health effects was not provided. The dose coefficients used in the L3PRA project are based on an update of the FGRDCF methodology performed for the SOARCA project. This SOARCA (and L3PRA) methodology allows consideration of the updated dosimetry from Federal Guidance Report 13 (EPA 1999). The dose coefficient file set used in this analysis, FGR13GyEquivDCF.INP together with its annual dose file set, contains dose coefficients based on FGR-12 and FGR-13 for 825 radionuclides, 26 organs and the whole body effective dose, and five types of exposure (groundshine, cloudshine, acute inhalation, chronic inhalation, and ingestion).[36] In order to determine the level that various dose and dose rates contribute to health effects (see Section 3.6.2), MACCS has the ability to implement an annual dose and dose-rate model to exclude low dose and dose rates from the calculation. For this purpose, a set of 50 files containing annual internal dose coefficients (i.e., the internal dose in years 1-50 after exposure) from the inhalation or ingestion pathways are used to determine the annual dose contribution of these pathways to the dose-response model. No additional data is needed for the external pathways, because these dose coefficients do not change with time.

[36] The DCF file also contains dose coefficient columns for an 8-hr and 7-day cumulative groundshine dose for backwards compatibility with the original version of MACCS. These fields are no longer used in MACCS and a value of -1 is inserted in the MACCS DCF file.

3.5.2.1 *MACCS Organ Definitions*

Versions of the MACCS code up to and including version 3.10 contain a more limited set of organ dose quantities than are available in DCF files based on FGR-13. When a dose coefficient file based on FGR-13 is selected, MACCS considers one organ used to compute an effective dose, eight organs (including one “residual” organ used to represent organs not specifically identified) for stochastic effects from lifetime exposures, and six organs for deterministic effects from acute exposures. The mapping of MACCS dosimetric quantities and the organ name in the FGR13GyEquivDCF.INP dose coefficient file is shown in Table 3.5-1.

Table 3.5-1: MACCS organs and dosimetric quantities

FGR-13 DCF File Organ Name	MACCS Acute Dose Quantity	MACCS Lifetime Dose Quantity
ICRP60ED		L-ICRP60ED
THYROID	A-THYROID	L-THYROID
RED MARR	A-RED MARR	L-RED MARR
LUNGS	A-LUNGS	L-LUNGS
LOWER LI	A-LOWER LI	L-LOWER LI
STOMACH	A-STOMACH	
SKIN	A-SKIN	
BONE SUR		L-BONE SUR
BREAST		L-BREAST
LIVER		L-LIVER
BLAD WAL*		L-BLAD WAL*

**In the FGR13GyEquivDCF.INP DCF file, the organ named bladder wall, and therefore the MACCS dosimetric quantity L-BLAD WAL, actually contain dose coefficients for the pancreas, which has been selected as a representative soft tissue for the dose to residual organs not included in the MACCS list of cancer sites.*

Due to a limitation of eight lifetime dose coefficients representing specific organs (excluding the effective pseudo-organ, L-ICRP60ED) that are read from the DCF file, MACCS calculates the dose to seven specific cancer sites and one residual cancer site. To estimate residual cancers, the dose coefficients for the pancreas are used as a surrogate for dose to soft tissue. Because MACCS does not currently read the data for the pancreas from the dose coefficient file, values of the dose coefficients for the pancreas were copied into the organ called bladder wall. Thus, residual cancers are associated with the organ called bladder wall, which actually contains dose coefficients for the pancreas.

3.5.2.2 *Dose Coefficient File*

A dose coefficient for external exposure is a factor that relates the quantity of a radioactive isotope in an environmental media outside of the body, such as soil or air, to the radiation dose received. A dose coefficient for ingestion is a factor that relates the quantity of a radioactive isotope ingested to the radiation dose received. Likewise a dose coefficient for inhalation is a factor that relates the quantity of a radioactive isotope inhaled to the radiation dose received.

The dose coefficient file contains data on dose coefficients for each radionuclide and organ for each of the following exposure types:

- cloudshine dose-rate factor [Sv/(Bq-s/m3)]
- groundshine dose-rate factor [Sv/(Bq-s/m2)]
- "acute" short-term inhalation doses (Sv/Bq) used for calculation of deterministic health effects
- "lifetime" 50-year committed inhalation doses (Sv/Bq) used for calculation of effective doses and stochastic health effects
- 50-year committed ingestion doses (Sv/Bq) used for calculation of effective doses and stochastic health effects from food and water ingestion

For computing deterministic health effects, the dose-rate factors for cloudshine and groundshine are used with the appropriate exposure period, and the acute inhalation dose column is used. If an organ is not considered in the deterministic health effects models, no internal dose for early exposure from inhalation is given, or needed; the values in the file are set to −1.0. For computing latent health effects or effective doses, the dose-rate factors for cloudshine and groundshine are used with the appropriate exposure period, and the lifetime committed inhalation and ingestion dose coefficients are used.

The dose coefficients used in this analysis are based on an update of the FGRDCF methodology that allows consideration of the updated dosimetry from Federal Guidance Report 13. The updated methodology allows both a consideration of the acute effects due to short-term exposure, as well as the ability to consider annual doses and committed doses. The dose coefficient file set used in this analysis, FGR13GyEquivDCF.INP together with its annual dose file set, contains dose coefficients based on FGR-12 and FGR-13 for 825 radionuclides, 26 organs and the whole body effective dose, and five types of exposure (groundshine, cloudshine, acute inhalation, chronic inhalation, and ingestion).[37] Federal Guidance Report 13 (FGR-13) is primarily concerned with cancer risk from environmental exposure to radionuclides. However, it includes data files providing absorbed dose rate versus time for ingestion and inhalation intakes of radioactive material in addition to risk coefficients. The internal dose coefficient values reflect integrated or cumulative absorbed doses following an instantaneous intake. They are calculated from the instantaneous absorbed dose rate versus time data contained in the data files *fgr13inh.drt* and *fgr13ing.drt*, which are contained in the CD supplement to Federal Guidance Report 13 (EPA 2002). The dose-rate data for adult members of the public were numerically integrated and then weighted by the relative biological effectiveness (RBE) appropriate for the radionuclide and exposure pathway.

[37] The DCF file also contains dose coefficient columns for an 8 hr and 7 day cumulative groundshine dose for backwards compatibility with the original version of MACCS. These fields are no longer used in MACCS and a value of -1 is inserted in the MACCS DCF file.

3.5.2.3 *External Dose Coefficients*

External dose pathways (cloudshine and groundshine) are quantified using dose coefficients providing the dose rate as a function of the environmental concentration (Sv/s per Bq/m^3 or Sv/s per Bq/m^2, respectively). The MACCS external dose coefficients are consistent with those provided in Federal Guidance Report 12 (FGR-12) Table III.1 (Dose Coefficients for Air Submersion) and Table III.3 (Dose Coefficients for Exposure to Contaminated Ground Surface) (EPA 1993). As described in FGR-12, the dose coefficients of Table III.3, for exposure to a contaminated ground surface, assume that the source region is a smooth plane and does not take into account the effects of ground roughness in reducing external dose equivalents. These values should be adjusted to account for ground roughness. As reported in FGR-12, dose-reduction factors for a photon spectrum representative of deposited radionuclides following releases from nuclear reactors are given by (Burson and Profio 1977). These factors range from almost one for very smooth surfaces (such as paved areas) to about 0.5 for rough surfaces (such as deeply plowed fields), with a representative average value of about 0.7. The uncertainties in external dose coefficients was evaluated in Section 2.1.2 of (Eckerman 2012), who recommended (based on subjective judgment) that the uncertainty in the unshielded ground plane factors from FGR-12 could be represented by a multiplicative factor defined by a triangular distribution between 0.5 and 1.5, with a maximum value at 0.8. The dose coefficients used in the L3PRA project were taken from the DoseAndRisk.mdb database file in the CD supplement to FGR-13 (EPA 2002). Only the dose coefficients for a reference adult were extracted from the database file.

Because the external dose coefficients are provided as instantaneous dose rates rather than doses integrated over time following intake, the same values may be used for computing both acute and latent health effects. Doses are accumulated by MACCS over the exposure period computed by the code or provided by the user. When calculating early health effects, all external dose delivered during the emergency phase of the accident is treated as though it had been delivered during the first day of the emergency phase.

3.5.2.4 *Acute Inhalation Dose Coefficients*

Acute inhalation dose coefficients are supplied only for the organs used for calculating deterministic health effects from acute exposures: stomach wall, small intestine, lower large intestine, red marrow, thyroid, and lungs. MACCS takes into account dose commitments for up to the first year after radionuclides are inhaled. The other organs in the dose coefficient file have been given effective acute dose coefficients of –1.0, which prevents their inadvertent use, since any resulting doses would be negative.

Biokinetic Assumptions

The inhalation coefficients for aerosols in the FGR13GyEquivDCF.INP file assume an activity median aerodynamic diameter of 1 μm, a geometric standard deviation of 2.5, a density of 3 g/cm^3, and a shape factor of 1.5. The FGR-13 system of dosimetry is based on a newer model of the lung than are the DOSFAC2 coefficients, and the lung clearance class symbols have

changed. The elements used in DOSFAC2 files that had lung clearance classes of years (Y), months (M), or days (D) were assigned lung absorption types of slow (S), moderate (M), or fast (F), respectively. The classifications are provided in Table 3.5-2. The lung absorption type for aerosols are consistent with (Runkle and Ostmeyer 1985) for severe accidents at light water reactors. The dose factor files do not show a lung absorption type for certain isotopes when either there was no choice of absorption type in FGR-13, or the choice was superfluous because the inhalation dose coefficients were zero. The lung absorption type for a specific radionuclide may be viewed by opening the DCF file and reading the corresponding value in lines 32 through 856. This information is for the benefit of the code users; it is not used by the MACCS computer code. The uptake fraction via the digestive tract, f_1, for an element affects the dose coefficients for inhalation of radioactive materials. The inhalation dose coefficient is dependent on f_1 because when an intake via inhalation occurs, some of the material that is cleared from the respiratory tract is swallowed and is available for uptake via the digestive tract. The FGR-13 inhalation dose-rate data file, *fgr13ing.drt*, only included one f_1 value for each lung absorption type. Thus, once the lung absorption types were chosen for consistency with (Runkle and Ostmeyer 1985), there was no additional choice of the f_1 value to use for inhalation coefficients for each isotope.

Table 3.5-2: Lung absorption type and gastrointestinal uptake fractions (f1)

Elem.	Lung Absorp. Type	f_1	Elem.	Lung Absorp. Type	f_1	Elem.	Lung Absorp. Type	f_1
Ac	S	0.0005	Ga	M	0.001	Pu	S	0.00001
Ag	S	0.01	Gd	M	0.0005	Ra	M	0.1
Al	F	0.01	Ge	M	1	Rb	F	1
Am	M	0.0005	H	WV	1	Re	M	0.8
As	M	0.5	Hf	F	0.002	Rh	S	0.05
At	F	1	Hg	V	0.02	Ru	S	0.01
Au	S	0.1	Ho	M	0.0005	S	F	0.8
Ba	F	0.2	I	F	1	Sb	F	0.1
Be	S	0.005	In	M	0.02	Sc	S	0.0001
Bi	M	0.05	Ir	S	0.01	Se	M	0.1
Bk	M	0.0005	K	F	1	Si	M	0.01
Br	F	1	La	M	0.0005	Sm	M	0.0005
C	F	1	Lu	S	0.0005	Sn	M	0.02
Ca	M	0.1	Md	M	0.0005	Sr	F	0.3
Cd	S	0.05	Mg	M	0.5	Ta	S	0.001
Ce	S	0.0005	Mn	M	0.1	Tb	M	0.0005
Cf	S	0.0005	Mo	S	0.01	Tc	M	0.1
Cl	F	1	Na	F	1	Te	M	0.1
Cm	M	0.0005	Nb	S	0.01	Th	S	0.0005
Co	S	0.01	Nd	S	0.0005	Ti	S	0.01
Cr	S	0.1	Ni	M	0.05	Tl	F	1
Cs	F	1	Np	M	0.0005	Tm	M	0.0005

Note: Absoro.: Absorption

Table 3.5-2: Lung absorption type and gastrointestinal uptake fractions (f1) (continued)

Elem.	Lung Absorp. Type	f1
Cu	S	0.5
Dy	M	0.0005
Er	M	0.0005
Es	M	0.0005
Eu	M	0.0005
F	S	1
Fe	M	0.1
Fm	M	0.0005
Fr	F	1

Elem.	Lung Absorp. Type	f1
Os	S	0.01
P	F	0.8
Pa	S	0.0005
Pb	F	0.2
Pd	S	0.005
Pm	S	0.0005
Po	M	0.1
Pr	S	0.0005
Pt	F	0.01

Elem.	Lung Absorp. Type	f1
U	S	0.002
V	M	0.01
W	F	0.3
Y	S	0.0001
Yb	S	0.0005
Zn	S	0.01
Zr	M	0.002

Note: Absoro.: Absorption

Relative Biological Effectiveness and Composite Organs

The dose-rate files provide the absorbed dose, measured in SI units of Gray (Gy), to different organs. However, the biological effectiveness of different kinds of radiation can be different, with high linear energy transfer (LET) radiation, such as alpha radiation, causing more biological damage for the same level of absorbed dose. This effect is accounted for by assigning a relative biological effectiveness (RBE) for different types of radiation. For computing stochastic effects, the International Commission on Radiological Protection (ICRP) has provided experimental relative biological effectiveness and radiation weighting factor values (ICRP 2003). When an absorbed dose in Gray is weighted by the standard set of ICRP radiation weighting factors, the resulting value is known as the equivalent dose and is reported in Sieverts (Sv). Because there is no SI term for the quantity obtained by weighting an absorbed dose in Gray by a different relative biological effectiveness than those recommended by the ICRP, MACCS uses the terminology “Gray-Equivalent” to designate an absorbed dose weighted by a non-standard RBE. For acute doses from inhalation, an RBE value of 10 is assigned to compute a Gray-equivalent absorbed dose for alpha-emitting radionuclides for all organs. This is consistent with the methodology described in (Jow et al. 1990) for the original MACCS code.

Alpha emitters, such as uranium-238, which have high-LET and low-LET components have two sets of dose coefficients. The low-LET (beta and gamma radiation) and high-LET (alpha radiation) absorbed dose rates as a function of time were separately numerically integrated to obtain low-LET and high-LET absorbed dose coefficients for each isotope. Other isotopes, such as cesium-137 had only a low-LET set of coefficients. The high-LET and low-LET absorbed dose coefficients were combined into a single dose as follows:

$$DCF_{j,t,o} = w_{Low,o} * DCF_{Low,j,t,o} + w_{High,o} * DCF_{High,j,t,o}$$

Where DCF is the dose coefficient, “w” is the radiation weighting factor (i.e., RBE), “j” represents the isotope, “t” represents the commitment period, and “o” represents the organ.

The lung (i.e., the thoracic portion of the respiratory tract) is not included directly in the fgr13inh.drt file, but is represented by the following thoracic respiratory tract tissues: bronchial (BB), bronchiolar (bb), alveolar-interstitial (AI), and thoracic lymph nodes (LNTH). The dose coefficient for the lung was calculated using the method described in ICRP Publication 66, page 35, Equation 2 (ICRP 1994). This builds up the lung coefficient from coefficients for the thoracic respiratory tract tissues as follows:

$$DCF_{Lung} = 0.333(DCF_{BB} + DCF_{bb} + DCF_{AI}) + 0.001\, DCF_{LNTH}$$

Dose Rate Interpolation and Integration

An interpolation scheme was needed to perform the time integrals to evaluate dose commitment periods. Different options for interpolating the absorbed dose-rate data in the data file *fgr13inh.drt* file were considered. Attempts at constructing curves using 2nd or 3rd order interpolation resulted in negative instantaneous dose rates at some times. Logarithmic transformation of the data prior to interpolation was not an option, because of the frequent occurrence of zero values in the datasets. The method chosen was to employ 1^{st} order or simple linear interpolation. Overall, this is expected to slightly overestimate the internal dose coefficients.

Inhalation of radioactive materials results in protracted exposures leading to doses delivered at later times and lower dose rates. Doses delivered at later times and lower dose rates are not as effective at inducing acute effects when compared to doses delivered during earlier time periods at higher dose rates. For example, for bone marrow death (with supportive treatment), (Evans et al. 1985) show LD_{50} values of 4.5 Gy for the 0 to 1 day time period, 9 Gy for the 1 to 14 day time period, and 18 Gy for the 14 to 30 day time period. Instead of calculating three different red marrow doses and applying the three different values of LD50 to calculate risk, a single red marrow dose using effective acute dose coefficients in calculated. So, according to Table 3.5-3, effective acute red marrow dose is 100 percent of the first day's dose, 50 percent of the next 13 days' dose, and 25 percent of the next 16 days' dose. This effective acute dose is then used in the risk equation in conjunction with the LD_{50} for the 0- to 1-day time period to obtain the hazard to bone marrow. The dose coefficients for acute inhalation were therefore adjusted using dose-reduction factors for protracted doses in order to reduce the computational demands of the calculations. These factors were derived using the procedures outlined in Section 6.1.3 of (Jow et al. 1990) and Section 6.7 of (Chanin and Young 1998a). Weighting of the integrated doses computed from the instantaneous dose rates yield a MACCS dosimetric quantity referred to as the "effective acute dose." The effective acute dose, D_e, is that dose, which if delivered entirely in 1 day, would induce the same acute health effects as an actual dose delivered over many days. The effective acute dose coefficient used by MACCS is given by

$$F_e = \sum_t \left[\left(\frac{\alpha_1}{\alpha_t}\right) \times F_t\right]$$

Where

F_e	=	the effective acute dose coefficient
F_t	=	the dose coefficient for the actual dose D_t delivered in time period t
α_t	=	the LD_{50} for time period t
α_1	=	the LD_{50} for a time period of 1 day

The acute effective dose for an isotope and an organ is therefore a weighted sum of the acute dose coefficients for a number of shorter time periods: 0 to 1 day, 1 to 7 days, 7 to 14 days, 14 to 30 days, 30 to 200 days, and 200 to 365 days. The weighting factors (i.e., α_1/α_t) applied in the effective acute dose calculations are shown in Table 3.5-3, based on health effects data from the NUREG/CR-4214 series of reports (Evans et al. 1985, 1993).

Table 3.5-3: Acute dose-reduction factors (α_1/α_t) (unitless)

Start Time (d)	End Time (d)	Stomach Wall	Small Intestine Wall	Lower Large Intestine Wall	Red Marrow	Thyroid	Lungs
0	1	1	1	1	1	1	1
1	7	0.37	0.43	0.43	0.5	0.2	0.0625
7	14	0	0	0	0.5	0.2	0.0625
14	30	0	0	0	0.25	0.2	0.027
30	200	0	0	0	0	0	0.027
200	365	0	0	0	0	0	0.0109

3.5.2.5 *Chronic Inhalation and Ingestion Dose Coefficients*

The chronic inhalation and ingestion dose coefficients contained in FGR13GyEquivDCF.INP are used to estimate long-term doses for purposes of estimating cancer risk. These coefficients are based on models for an adult member of the public provided in FGR-13.

Biokinetic Assumptions

For computing committed inhalation doses, the biokinetic assumptions used for computing acute inhalation DCFs (activity median aerodynamic diameter of 1 μm, a geometric standard deviation of 2.5, a density of 3 g/cm^3, a shape factor of 1.5, and lung absorption types as given in Table 3.5-2) are also used for computing the chronic inhalation DCFs. For computing committed ingestion doses, the uptake fraction via the digestive tract, f_1, for an element affects the dose coefficients for ingestion. The ingestion dose coefficient is dependent on f_1 because a form of a radioactive substance that can be absorbed effectively through the digestive tract can cause a higher radiation dose than a less soluble form. FGR-13 assigned f_1 values for ingestion based on the form expected to persist in the environment, and these values are not necessarily consistent with the f_1 values used in the computation of inhalation dose coefficients. In the computation of ingestion dose coefficients, there were choices of f_1 to be made for only three

elements: hydrogen, mercury, and polonium. The ingestion dose coefficients are based on the f_1 values provided in Table 3.5-4.

Table 3.5-4: Chemical forms and f_1 values assumed for ingestion dose coefficients

Elem.	Form	f1
Ac		0.0005
Ag		0.05
Al		0.01
Am		0.0005
As		0.5
At		1
Au		0.1
Ba		0.2
Be		0.005
Bi		0.05
Bk		0.0005
Br		1
C		1
Ca		0.3
Cd		0.05
Ce		0.0005
Cf		0.0005
Cl		1
Cm		0.0005
Co		0.1
Cr		0.1
Cs		1
Cu		0.5
Dy		0.0005
Er		0.0005
Es		0.0005
Eu		0.0005
F		1
Fe		0.1
Fm		0.0005
Fr		1
Ga		0.001
Gd		0.0005
Ge		1
H	Tritiated Water	1
Hf		0.002
Hg	Inorganic	0.02
Ho		0.0005
I		1
In		0.02
Ir		0.01
K		1

Elem.	Form	f1
La		0.0005
Lu		0.0005
Md		0.0005
Mg		0.5
Mn		0.1
Mo		1
Na		1
Nb		0.01
Nd		0.0005
Ni		0.05
Np		0.0005
Os		0.01
P		0.8
Pa		0.0005
Pb		0.2
Pd		0.005
Pm		0.0005
Po	Soluble	0.5
Pr		0.0005
Pt		0.01
Pu		0.0005
Ra		0.2
Rb		1
Re		0.8
Rh		0.05
Ru		0.05
S		1
Sb		0.1
Sc		0.0001
Se		0.8
Si		0.01
Sm		0.0005
Sn		0.02
Sr		0.3
Ta		0.001
Tb		0.0005
Tc		0.5
Te		0.3
Th		0.0005
Ti		0.01
Tl		1
Tm		0.0005
U		0.02

Elem.	Form	f1
V		0.01
W		0.3
Y		0.0001
Yb		0.0005
Zn		0.5
Zr		0.01

Relative Biological Effectiveness and Composite Organs

For computing stochastic effects in the "Gray-equivalent" DCF file sets, FGR13GyEquivDCF.inp and FGR13GyEquivDCF01.inp through FGR13GyEquivDCF50.inp, $w_{High,o}$ was assigned a value of 20 for 50-year or annual dose commitment factors in all organs except red marrow and breast. In the case of red marrow, $w_{High,o}$ had a value of 1 in the 50-year and annual dose coefficients. In the case of breast, $w_{High,o}$ had a value of 10 in the 50-year and annual dose coefficients. Since the radiation weighting factors were assigned values different than the standard radiation weighting factors for high-LET radiation in this set of files, they are more properly referred to as relative biological effectiveness (RBE) factors. The particular radiation weighting factors for the red marrow and breast are based on recommendations made in Federal Guidance Report 13. These adjustments are necessary and consistent with those recommended in EPA's Estimating Radiogenic Cancer Risks document (EPA 1994). Some of the organs shown in Table 3.5-1 were not included in the *fgr13ing.drt* or *fgr13ing.drt* files. The methods of calculating the DCFs for each of these organs are described in this section.

Lung	Inhalation and ingestion dose coefficients for the lung (i.e., the thoracic portion of the respiratory tract) were calculated using the method described in ICRP Publication 66, page 35, Equation 2. This builds up the lung coefficient from coefficients for the following thoracic respiratory tract tissues: bronchial (BB), bronchiolar (bb), alveolar-interstitial (AI), and thoracic lymph nodes (LNTH). $$DCF_{Lung} = 0.333(DCF_{BB} + DCF_{bb} + DCF_{AI}) + 0.001\ DCF_{LNTH}$$
Extra-Thoracic Respiratory Tract	The extra-thoracic respiratory tract tissues consist of the anterior nose (ET_1), posterior nasal passages, larynx, pharynx, mouth (ET_2), and extra-thoracic lymph nodes (LN_{ET}). Inhalation and ingestion dose coefficients for the extra-thoracic region of the respiratory tract, ET_{Reg}, were calculated using ICRP Publication 66, page 35, Equation 1. $$DCF_{ET} = 0.001\ DCF_{ET_1} + 0.001 DCF_{LN_{ET}} + DCF_{ET_2}$$
Esophagus	The esophagus was assigned the corresponding inhalation and ingestion dose coefficients of the thymus (this was recommended by Dr. Rich Leggett, ORNL Center for Biokinetic and Dosimetric Research).
Colon	The DCF for the colon is a weighted sum of the dose coefficients for the lower and upper large intestine (LLI and ULI), as described in footnotes to Table 3.6.1 in ICRP Publication 71 (ICRP 1995). $$DCF_{Colon} = 0.57\ DCF_{ULI} + 0.43\ DCF_{LLI}$$
Gonads	Inhalation and ingestion dose coefficients for gonads that appear in the FGR13DCF.inp and FGR13GyEquivDCF.inp files were the greater of the dose coefficients to the testes and ovaries. This is consistent with the convention that was followed by ICRP Publication 71 (see paragraph 20 of [ICRP 1995]).

Tissue Weighting for Effective Dose Computations

The effective dose (ICRP60ED) is used internally by MACCS for simulating protective action decisions based on dosimetric quantities computed under a system of radiation protection. It is also used in the threshold dose-response models to determine whether an annual or lifetime dose has been exceeded. Although it is not used to compute cancer fatalities, which are

computed based on organ-specific dose equivalent doses together with organ-specific risk factors, it is also used as the measure to compute the collective population dose. The effective dose, *E*, is a weighted sum of the equivalent doses to the various organs (H_T). Because the weighting factors are normalized to sum to 1.0, a weighting factor for tissue *T* corresponds to the fractional contribution of that tissue to the total risk of stochastic health effects when the body is uniformly irradiated. The effective dose, *E*, is widely used for compliance assessment purposes and for making rough dose estimates of cancer risk. However, although the risk of developing cancer from radiation exposure is roughly proportional to *E*, it should not be used in formal radiation risk assessment calculations and is therefore not used in the MACCS code to estimate latent health impacts. MACCS uses the Gray-Equivalent doses discussed earlier to compute cancer risks for individual organs, and then sums the results over all organs to estimate the total number of cancers.

MACCS uses effective radiation dose coefficients for inhalation, ingestion, and external radiation based on the ICRP Publication 60 system of organ weighting factors, w_T, which are provided in Table 3.5-5. Table 3.5-5 also provides a cross reference between the organ name listed in ICRP 60, the organ name used in MACCS, and the organ names tabulated in the FGR-13 based DCF files. As is evident from Table 3.5-5, the MACCS code uses a more limited set of organ dose quantities than are available in the DCF file based on FGR-13. MACCS considers nine organs for stochastic effects from chronic exposures. The mapping of MACCS dosimetric quantities and the organ name in the FGR13GyEquivDCF.INP dose coefficient file is shown below.

Table 3.5-5: Organ names and ICRP 60 tissue weighting factors.

ICRP Organ Name	Organ Name in FGR13DCF File	Tissue Weighting Factor, W_T	MACCS Lifetime Dose Quantity
Gonads	GONADS	0.2	--
Bone marrow (red)	RED MARR	0.12	L-RED MARROW
Colon	COLON	0.12	--
Lung	LUNGS	0.12	L-LUNGS
Stomach	STOMACH	0.12	--
Bladder	BLAD WAL	0.05	L-BLAD WAL
Breast	BREAST	0.05	L-BREAST
Liver	LIVER	0.05	L-LIVER
Esophagus	ESOPHAGUS	0.05	--
Thyroid	THYROID	0.05	L-THYROID
Skin	SKIN	0.01	--
Bone surface	BONE SUR	0.01	L-BONE SUR
Remainder	REMAINDER	0.05	--
Lower Large Intestine	LOWER LI	--	L-LOWER LI
Effective Dose	ICRP60ED	--	L-ICRP60ED

The dose coefficients for “Remainder” cannot be calculated until the dose coefficients for all of the organs have been calculated. The dose coefficients for “Remainder” were calculated using the logic presented on page 4 of ORNL/TM-2003/207 (Leggett and Eckerman 2003). Although

"Remainder" is listed as one of the organs in Table 3.5-5, it is not actually a specific organ. For a specific isotope, the calculation of the dose coefficient for the tissue "Remainder" is based on the following rules:

1. "Remainder" is composed of the following tissues: adrenals, brain, extra-thoracic airways, small intestine, kidneys, muscle, pancreas, spleen, thymus, and uterus.
2. The value 0.05 is applied to the mass-weighted average dose to the "Remainder" tissue group, except when the "splitting rule" applies.
3. If a tissue or organ in the "Remainder" list receives a dose greater than that received by every one of the 12 tissues in Table 1, then the splitting rule applies. In this case a weighting factor, w_T, of 0.025 (half of "Remainder") is applied to that tissue and 0.025 is applied to the mass-averaged committed equivalent dose in the rest of the "Remainder" tissues.

Once the "Remainder" DCF has been determined for each radionuclide, the corresponding DCFs for "Effective Dose" were calculated using the tissue weighting factors shown in Table 3.6.1 of ICRP 71 and the individual organ dose coefficients.

Dose Rate Interpolation and Integration

For chronic inhalation exposures and for ingestion exposures (for which only chronic exposures are considered credible), the dose rates were integrated over 50 years to compute the committed doses, and were integrated over the specified year for the annual dose coefficient files. With the LNT model, doses are calculated for a 50-year commitment period following an intake of radioactive materials during the entire exposure period used in the calculation. The LNT dose model is used when there is no need to account for the possibility of a dose or dose-rate threshold below which there is assumed to be no latent-cancer risk and there is no need to tally dose by the year that the radiation dose is received.

For the threshold or piecewise-linear models, a simple dose commitment cannot be used and the annual doses need to be tracked. The file set, FGR13GyEquivDCFxx.inp, consists of a set of 50 files that contain annual dose commitment coefficients for the internal dose pathways. The dose coefficient file naming convention is such that FGR13GyEquivDCF01.inp contains annual ingestion and inhalation coefficients that can be used to provide the ingestion and inhalation doses received in the first year from an intake that is assumed to occur at the beginning of the first year. FGR13GyEquivDCF02.inp contains ingestion and inhalation coefficients that can be used to provide the ingestion and inhalation doses received in the second year from an intake that is assumed to occur at the beginning of the first year. In general, file FGR13GyEquivDCF*XX*.inp contains ingestion and inhalation coefficients that can be used to provide the ingestion and inhalation doses received in the year *XX* from an intake that occurred at the beginning of the first year. Annual dose coefficients allow dose to be tallied by the year the dose is received, instead of the year the intake occurs.

3.5.3 MACCS Dosimetry Input Parameter Summary

A summary of the MACCS input parameters related to dosimetry is provided in Table 3.5-6.

Table 3.5-6: Summary of MACCS input parameters related to dosimetry

Variable	Description	Value	Source
DCF_FILE	Name of dose coefficient file	FGR13GyEquivDCF.INP	Section 3.5
ORGFLG	Doses to be calculated for specified organ	All TRUE for FGR-13	

3.5.4 Identification and Discussion of Uncertainties Related to Dosimetry

There are a numbers of sources of uncertainty in the calculation. These are listed in Table 3.5-7 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.5-8 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.5-7. A candidate sensitivity analysis has only been identified for those uncertainties that are considered readily amenable to quantitative modeling using MACCS.

Information on the uncertainties in parameters for internal dosimetry models was evaluated in (Goossens et al. 1998). An evaluation of the uncertainties in the MACCS dose coefficients is discussed in Section 2.1.5 of (Eckerman 2012), based on the analyses in (Pawel et al. 2007). Tables of the geometric mean and standard deviations for inhalation intakes in the dose factors are provided in Appendix B of (Eckerman 2012) for 58 radionuclides and the eight MACCS cancer sites. Uncertainties in the ingestion coefficients were not considered in that report as the SOARCA project did not model the ingestion pathway. The dominant sources of uncertainties in the inhalation dosimetric models were considered to include the fraction of inhaled material deposited in the respiratory tract, the rate of absorption from the respiratory tract to blood, the gastrointestinal absorption fraction (f1), the systemic biokinetic model, and specific energy values for certain combinations of source and target organs and radiation types. Uncertainties in dosimetric quantities related to both groundshine and chronic inhalation doses were investigated in (SNL 2016) and (SNL 2019). For the releases analyzed in those scenarios, uncertainties in groundshine and long-term inhalation dosimetry generally did not show up as a significant source of uncertainty for health risks.

Table 3.5-7: Uncertainties related to dosimetry

3.5.2.1 MACCS Organ Definitions	The organ list in MACCS is based on the organs for which risk factors were provided in FGR-11/12. The mapping of risk information from FGR-13 to the reduced set of organs in MACCS is a source of model uncertainty.
3.5.2.2 Dose Coefficient File	Uncertainties in the dosimetric (e.g., biokinetic parameters) models would propagate forward into the DCF file. Also, the chemical and physical form of inhaled or ingested material will affect the intake, deposition, and distribution of inhaled material within the body. Sources of uncertainty in internal dosimetry were identified and discussed in (Goossens et al. 1998), as well as in FGR-13 and in (Eckerman 2012).
3.5.2.3 External Dose Coefficients	Any uncertainties in the calculation of external dose coefficients would propagate forward into the calculation. Also, external dose coefficients are based on exposure from an ideal uniform surface. As discussed previously, the surface on which the material is deposited is likely to be nonuniform. Sources of uncertainty in external dosimetry were discussed in (Goossens et al. 1997).
3.5.2.4 Acute Inhalation Dose Coefficients	The inhalation dose coefficient is modeled based on an instantaneous intake of inhaled material. The effect of a more continuous or time-dependent intake is not modeled. Also, there could be uncertainties in the weighting factors the absorbed dose rates used to assess the effect of dose fractionation from inhaled materials. Sources of uncertainty in early health effects, which can arise from acute inhalation exposures, were discussed in (Haskins et al. 1997).
3.5.2.5 Chronic Inhalation and Ingestion Dose Coefficients	The dose coefficients are modeled based on an instantaneous intake of material. The effect of a more continuous or time-dependent intake is not modeled. Sources of uncertainty in late health effects, which can arise from chronic exposures, were discussed in (Little et al. 1997). The effects of uncertainties in inhalation dose coefficients were analyzed as part of the SOARCA uncertainty analyses (SNL 2016 2019).

Table 3.5-8: Potential sensitivity analyses to address uncertainties related to dosimetry

Analysis	Objective	MACCS Parameters to be Varied	Expected Results	Implementation Method
DO_1	Examine influence of shielding factors on results	Shielding factors (GSHFAC/PROTIN/CSFACT)	All impacts expected to be proportional to shielding assumptions	Cyclic file set
DO_2	Examine uncertainty associated with inhalation DCF values	DCF values sampled using values from Appendix B of (Eckerman, 2012)	Limited impacts because long-term doses dominated by groundshine	WinMACCS sampling
DO_3*	Examine the effect of explicitly modeling all organs identified in FGR-13 cancer risk models	DCF file, CFRISK/CIRISK, ORGFLG	Total cancer risk results not expected to change significantly.	Alternate input decks

**DO_3 would take advantage of the capabilities introduced with WinMACCS 3.11 to explicitly model risks to any organ specified in the DCF file, rather than the nine hardwired organs available in WinMACCS 3.10 and earlier.*

3.6 Health Effects (HE)

3.6.1 Assumptions and Known Limitations

- The availability of health effects models is limited to the capabilities incorporated into the MACCS code.
- Early injuries will be modeled to aid in evaluating margin to early fatality effects.
- The effect of low doses on health is uncertain. A linear, no threshold (LNT) dose-response model will be used, which assumes that any radiation exposure at all carries some risk of latent cancer.
- The mortality risk coefficients are based on an average over the age and gender of the U.S. population.
- Mortality risk coefficients for the cancer sites are assumed to be independent and not correlated.
- The uncertainty in the cancer mortality risk coefficient is assumed to be lognormally distributed.

3.6.2 Technical Discussion

As discussed in Section 3.5, MACCS considers two types of health effects: deterministic health effects arising from acute exposures during the early phase of an accident, and stochastic health effects arising from lifetime exposures from all phases of the accident. The health effects models in MACCS are based on the models described in the NUREG/CR-4214 series of reports (Evans et al. 1985, as updated), and as reflected in Section 6 of (Jow et al. 1990) and Sections 6.7 to 6.9 of (Chanin and Young 1998a).

The models presented in the reports referenced above provide estimates of the likelihood that an exposed individual may experience a specific health effect (e.g., lung impairment or breast cancer). Depending upon the exposure pathway, MACCS considers three types of populations: (1) individuals residing in the spatial elements surrounding the accident site (i.e., for the population specified on the computational grid) who are directly exposed to contaminated media (DIRECT), (2) individuals who reside in unspecified locations that consume food grown in, or drink water originating in, the spatial elements surrounding the accident site, who are therefore indirectly exposed to contaminated media (INDIRECT), and (3) decontamination workers (DECON). The set of pathways and exposure periods is summarized in Table 3.6-1. The distinction between the direct pathways and the indirect and decontamination pathways is used in the reporting of individual versus collective effects. Measures of individual risk of health effects are based only on the DIRECT pathways. Doses from these direct pathways are attributed to individual grid elements, and because the exposed population is confined to that grid element, estimates of individual risk can be made. Quantitative output for collective measures, such as population dose or total health effects cases, include all three types of populations. Although doses from indirect pathways (such as food or water ingestion or decontamination worker doses) are attributed to individual grid elements, they are not included in individual risk measures because the exposure population for these pathways may be very different from the population in that grid element.

Table 3.6-1: MACCS exposure pathways

Exposure Pathway	Early Phase	Late Phase
Cloud inhalation	DIRECT	n/a
Cloudshine	DIRECT	n/a
Groundshine	DIRECT	DIRECT, DECON
Inhalation of resuspended radionuclides	DIRECT	DIRECT
Skin dose	DIRECT	n/a
Food ingestion	n/a	INDIRECT
Water ingestion	n/a	INDIRECT

3.6.2.1 *Acute Health Effects*

The early health effect risk models implemented in MACCS are described in Section 6.1 of (Jow et al. 1990) and in Sections 6.7 and 6.8 of (Chanin and Young 1998a). These models are based on NUREG/CR-4214, Rev. 1, and have sigmoidal dependencies of individual risk on dose to the target organ in an exposed individual. These models have the following form:

$$r = 1 - e^{-\left(\ln(2)\cdot\left(\frac{D}{D_{50}}\right)^{\beta}\right)}, \qquad D > D_{Threshold}$$

$$0, \qquad D < D_{Threshold}$$

where
r = individual risk of health effect
β = shape parameter that determines the steepness of the sigmoidal dose-response curve
D = dose equivalent delivered to the target organ, computed as discussed in Section 3.5.1.1
D_{50} = dose equivalent that would induce the effect (impaired functioning of the target organ or fatality if the impairment is too large) in half the exposed population
$D_{Threshold}$ = dose equivalent below which the effect is not expected to occur

The individual risk of an early (sometimes referred to as prompt) fatality is modeled using a two-parameter Weibull function, which (Chanin and Young 1998a) refers to as a hazard function, H. The hazard function can be used to sum the cumulative risk from a number of potential types of damage as shown below. The exponential term represents the probability of surviving all "*i*" of the potential causes of radiation-related prompt fatality.

$$r = 1 - Exp\left[-\sum_i H_i\right]$$

$$H = \ln(2)\cdot\left(\frac{D}{D_{50}}\right)^{\beta}, \qquad D > D_{Threshold}$$

$$0, \qquad D < D_{Threshold}$$

where
r = individual risk of prompt fatality
β = shape parameter that determines the steepness of the sigmoidal dose-response curve.
D = dose equivalent delivered to the target organ, computed as discussed in Section 3.5.1.1
D_{50} = dose equivalent that would induce the effect (impaired functioning of the target organ or fatality if the impairment is too large) in half the exposed population.
$D_{Threshold}$ = dose equivalent below which the effect is not expected to occur

The MACCS early injury risk model provides an estimate of the risk of manifesting a single acute radiation injury. This is in contrast with the MACCS early fatality model, which provides a pooled risk estimate of death from any of several competing causes of early death.

Parameters representing acute health effects are derived from expert elicitation data documented in NUREG/CR-6545 (Haskins et al. 1997) or from the data in Sample Problem A based on the NUREG/CR-4214 series of reports (Evans et al. 1993; Abrahamson et al. 1989). Uncertainty distributions suitable for use in MACCS were developed in (Bixler et al. 2013) for all three of the fatal deterministic effects (hematopoietic, gastrointestinal, and pulmonary syndromes) and for pneumonitis, which represents a deterministic injury to the lung. In addition to the central tendency values that are used as the basis for the parameter estimates in this report, upper and lower bounds for early morbidity dose-response models are provided in Table 2.5 of (Evans et al. 1993). For the early health effect risks that are caused by external exposures (cloudshine and short-term groundshine exposures), the D_{50} value is chosen to be appropriate for intense exposures delivered over a 24-hour period to be consistent with the assumption that the dose is delivered during the first day of the emergency phase. As discussed in Section 3.5.5, for internal exposures due to inhalation of radioactive materials, dose protraction must be addressed, and the dose coefficient for acute inhalation was adjusted to provide an effective acute dose comparable to that of a 1-day dose. The values used in MACCS are shown in Table 3.6-2.

Table 3.6-2: Deterministic health effect dose-response parameters

Health Effect	Type	MACCS Dosimetric Quantity	$D_{Threshold}$ (Gy-Eq)[1]	D_{50} (Gy-Eq)[1]	Shape Factor	Source
Hematopoetic Syndrome	Fatality	A-RED MARR	2.32	5.6	6.1	(Bixler et al. 2013) (based on expert elicitation data from [Haskins et al. 1997])
Pulmonary Syndrome	Fatality	A-LUNGS	13.6	23.5	9.6	
Gastrointestinal Syndrome	Fatality	A-STOMACH	6.5	12.1	9.3	
Pneumonitis	Injury	A-LUNGS	9.2	16.6	7.3	

Table 3.6-2: Deterministic health effect dose-response parameters (continued)

Health Effect	Type	MACCS Dosimetric Quantity	$D_{Threshold}$ (Gy-Eq)[1]	D_{50} (Gy-Eq)[1]	Shape Factor	Source
Prodromal Vomiting	Injury	A-STOMACH	0.5	2	3	Sample Problem A (Chanin et al. 1990) (based on data summarized in [Evans et al. 1993, Table 2.5] and [Abrahamson et al. 1989])
Diarrhea	Injury	A-STOMACH	1	3	2.5	
Skin Erythema	Injury	A-SKIN	3	6	5	
Transepidermal Injury	Injury	A-SKIN	10	20	5	
Thyroiditis	Injury	A-THYROID	40	240	2	
Hypothyroidism	Injury	A-THYROID	2	60	1.3	

[1] *Gy-eq: Gray equivalent, which is the product of the absorbed dose in Gray and a relative biological effectiveness for deterministic effects*

3.6.2.2 *Stochastic Effects*

The MACCS models for cancer risk are discussed in Section 6.2 of (Jow et al. 1990), and in Section 6.9 of (Chanin and Young 1998a). Figure 3.6-1 depicts possible dependencies of cancer risk on dose for several of the models implemented in MACCS, such as the linear or linear-quadratic models. The figure shows that cancer risk is expected to increase generally with increasing dose. At sufficiently high doses, the functions of tissues, organs, and organ systems become compromised to the point that early fatalities from radiation injuries compete with cancer as a cause of death. Thus at high doses the risk of cancer as a cause of death appears to be reduced due to this competitive effect.

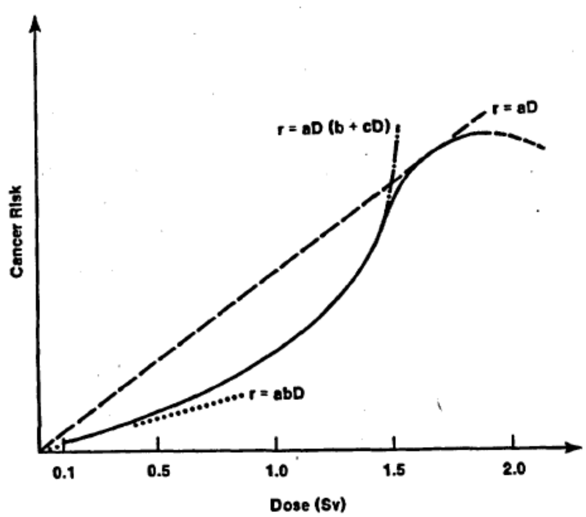

Figure 3.6-1: Plausible curves depicting cancer risk as a function of radiation dose
Source: reproduced from Figure 6.1 of (Jow et al. 1990)

Figure 3.6-1 also shows that below the region where early fatalities are competing with cancer as a cause of death, the dependence of risk on dose may not have a dose threshold. However, the dose-response curve is dotted below 0.1 Sv (10 rem) because data concerning cancer risks lack statistical power for doses that are this small (i.e., numbers of fatalities are indistinguishable from the background) and because extrapolation of data from larger exposures is questionable. This uncertainty is reflected in the Health Physics Society's position (HPS 2010) that cancer risks should not be estimated for such low doses by extrapolation of risk from data on larger doses.

MACCS has a variety of computational models to evaluate stochastic health effects. In each risk model, MACCS can account for early fatalities, if any, as a competing cause of death when calculating the cases of latent cancers in the surviving population. In practice, MACCS accomplishes this by adjusting the population size subject to latent cancer. The computational models of stochastic health effects include the following options:

- linear-quadratic model
- linear model
- piecewise-linear model
- dose and dose-rate threshold model

The first two of these are "No Threshold" dose-response models. They assume that any radiation exposure at all carries some risk of latent cancer. The MACCS base dose coefficient file used in SOARCA, FGR13GyEquivDCF.inp, is compatible with the "No Threshold" models. These models evaluate cancer risk based on equivalent committed doses to specific organs. The implementation of the linear-quadratic dose-response model was based on the recommendations of the BEIR III Committee (NAS/NRC 1980) and NRC-sponsored work (Evans et al. 1985). This model is described in Section 6.9.1 of (Chanin and Young 1998a). For the most part, there are no modern (currently recommended) linear-quadratic coefficients for evaluating cancer induction. However, MACCS retains a capability to use linear-quadratic risk models. Recently, the BEIR VII Committee's preferred risk model for leukemia was a linear-quadratic form in 2006 (NAS/NRC 2006). The linear-quadratic model is therefore retained as it is likely to be used in the future. The last two computational models, the piecewise-linear and dose threshold models, provide a mathematical implementation of dose-response models that depend on the doses received during annual periods. These models allow for the hypothesis that sufficiently low radiation doses during a year do not increase the risk of developing a latent cancer.

The cancer risk values for this analysis are those used in SOARCA and are based on "Radiation Dose and Health Risk Estimation: Technical Basis for the State-of-the-Art Reactor Consequence Analysis Project" (Eckerman 2012). As discussed in that report, the cancer risk model is based on the BEIR V Report (NAS/NRC 1990). In 1990, the BEIR V Committee adapted a linear latent-cancer-risk model and estimated a dose-rate effectiveness factor of 2. This factor was based on a conclusion that a dose from low linear energy transfer (LET) radiation received over a short period of time is more effective at causing cancer than the same dose received over an extended period of time. ICRP Publication 60 (ICRP 1991) expanded

upon the BEIR V recommendation and proposed a formal dose and dose-rate effectiveness factor (DDREF), as well as criteria for applying it. The recommendation of ICRP-60 was that DDREF should be 1 for doses of low-LET radiation when the dose rate is greater than a threshold (DDTHRE) of 0.1 Gray per hour and when the total dose is less than 0.2 Gray. Above these limits, it should have a value of 2 for low-LET radiation (ICRP 1991). The LMF-132 (Abrahamson et al. 1991) report concerning cancer risk assessment models adopted the ICRP recommendation. The MACCS computational model, described in Section 6.9.2 of (Chanin and Young 1998a), partially implements the recommendations of ICRP Publication 60 and LMF-132. As implemented in MACCS, there is not a test for whether dose rates exceed 0.1 Gray per hour. Furthermore, MACCS does not separately tally high- and low-LET radiation doses. The DDREF is implemented in MACCS as indicated below showing the individual risk of latent fatality:

Early Phase, D > DDTHRE	: $r_i = \alpha_i \bullet D$
Early Phase, D < DDTHRE	: $r_i = (\alpha_i / DDREFA) \bullet D$
Late Phase	: $r_i = (\alpha_i / DDREFA) \bullet D$

Where

r	individual risk of latent cancer of type i
D	Equivalent dose (Sv) computed using dose coefficients from the dose coefficient file
αi	Risk factor for cancer type i for incidence or mortality at high dose rate
DDREFA	Dose and dose-rate reduction factor for low doses or dose rates
DDTHRE	Dose threshold for application of the reduction factor in the early phase

The DDREFA is a dose and dose-rate reduction factor that appears in the denominator and reduces the health impact of low doses and dose rates. MACCS applies the DDREFA to all dose calculations in the CHRONC module because dose should always be less than 0.1 Gy per hour after the end of the emergency phase due to protective actions taken. For the early phase, where dose rates could be greater than 0.1 Gy per hour, the user defines the lifetime dose commitment (MACCS input parameter DDTHRE) below which the DDREF is applied to cancer risk calculations. Because of the way DDREFA is implemented in MACCS, the cancer induction risk factors (CIRISK and CFRISK) must be specified for the high-dose range (i.e., for doses above the value of DDTHRE). This can be confusing and attention is required when taking values from compilations of risk factors, such as Table S-3 of ICRP Publication 60. Some other codes and methods multiply the cancer induction risk factors by DDREFA when doses exceed the value of DDTHRE, and require the risk factors to be specified for the low-dose range.

Consistent with the SOARCA project, this analysis uses the linear piecewise model to implement the BEIR V linear, no threshold model for stochastic health effects. This is implemented by assigning the linear-quadratic parameters as follows: the threshold (ACTHRE) is equal to 0, the linear factor (DOSEFA) is equal to 1, and the quadratic factor (DOSEFB) is equal to 0. The cancer dose-response linear and quadratic factors (DOSEFA and DOSEFB,

respectively) are taken from BEIR V, which recommends a linear dose-response model for all cancer types.

Values for the dose and dose-rate effectiveness factors and risk coefficients were based on Table 3 of (Eckerman 2012). Eckerman (2012) included both best estimate values and estimates for the uncertainty in both the mortality risk coefficient and the dose and dose-rate effectiveness factor (DDREF) values. A DDREF value b_k (DDREFA) was applied to all doses in the late phase of the offsite consequence calculation and to those doses in the early phase that were less than a threshold value (DDTHRE) of 20 rem (0.2 Sv) to the whole body. The dose and dose-rate effectiveness factor used for all cancers except for the breast was 2.0, and for the breast was 1.0, as recommended in the BEIR V report. The DDREF for breast cancer reflects the linearity of the dose response observed in several study populations and an apparent invariance in risk with dose fractionation (EPA 1994). Information on the uncertainty in the cancer mortality risk coefficient, which is assumed to be lognormally distributed, is shown in Table 3.6-3 (adapted from Table 3 of (Eckerman 2012).

Table 3.6-3: Age- and gender-averaged cancer mortality risk coefficients for low-dose, low-LET uniform irradiation. Risk coefficients in units of 1/Gy

Cancer Site	Geometric Mean*	Geometric Standard Deviation	DDREF Probability Density Function	Confidence Interval	
				5^{th} percentile	95^{th} percentile
Leukemia	5.57E-03	1.23	f(x) =0.5, 1<x≤2 f(x) = 0.5*exp(2-x), 2<x<=8	2.4E-03	1.1E-02
Bone	9.50E-05	5.7		4.8E-06	1.7E-03
Breast	5.06E-03	2.21	f(x) = exp(1-x), x>1	1.0E-03	1.3E-01
Lung	9.88E-03	1.87	f(x) =0.5, 1<x≤2 f(x) = 0.5*exp(2-x), 2<x<=8	2.7E-03	3.2E-02
Thyroid	3.24E-04	4.15		2.7E-05	3.6E-03
Liver	1.50E-03	4.65		1.1E-04	2.0E-03
Colon	1.04E-02	2.26		2.2E-03	4.5E-02
Residual	2.46E-02	2.1		5.9E-02	9.5E-01

Source: adapted from Table 3 of (Eckerman 2012)
**Note, that except for breast, the values include a DDREF of 2.*

Note that the list of cancer sites in the MACCS model does not include all of the cancer sites evaluated in FGR-13. Note also the residual group in Table 3 includes, in addition to the residual group of FGR-13, cancers of the esophagus, stomach, skin, ovaries, bladder, and kidney. As noted earlier, it is assumed that the mortality risk coefficients for the cancer sites are independent and not correlated.

As discussed in (Eckerman 2012), the recommended risk factors used in SOARCA were taken from FGR-13 and have their origin in the BEIR V report. SOARCA added an additional cancer, liver cancer, and changed the name for cancer of the gastrointestinal tract, 'GI' in NUREG-1150, to colon cancer. Cancer risk factors based on the BEIR V report were chosen to be consistent with the dose coefficients. As discussed in Section 3.5, the dose coefficients used in this analysis are based on the latest Federal Guidance Report available, known as FGR-13, which

used risk factors from the BEIR V report. The values for use with the MACCS linear latent-cancer-risk model are given in Table 3.6-4.

Table 3.6-4: Stochastic health effect dose-response parameters

Cancer Type	MACCS Dosimetric Quantity	Dose Threshold (DDTHRE, Sv)	DDREFA	$\alpha_{FATALITY}$ (CFRISK, fatalities/Sv)*	$\alpha_{INCIDENCE}$ (CIRISK, incidence/Sv)*
LEUKEMIA	L-RED MARR	0.2	2	0.0111	0.0113
BONE	L-BONE SUR	0.2	2	0.00019	0.000271
BREAST	L-BREAST	0.2	1	0.00506	0.0101
LUNG	L-LUNGS	0.2	2	0.0198	0.0208
THYROID	L-THYROID	0.2	2	0.000648	0.00648
LIVER	L-LIVER	0.2	2	0.003	0.00316
COLON	L-LOWER LI	0.2	2	0.0208	0.0378
RESIDUAL	L-BLAD WAL**	0.2	2	0.0493	0.169

** Note that the risk coefficients CFRISK and CIRISK are provided for high doses/dose rates because of how the risks are computed within MACCS. For comparison with the more common low-dose/dose-rate risk coefficients, these values should be divided by the DDREFA values.*

***The organ named bladder wall in the DCF file, and the MACCS dosimetric quantity L-BLAD WALL, actually contain dose coefficients for the pancreas, which has been selected as a representative soft tissue for the dose to residual organs not included in the MACCS list of cancer sites.*

3.6.3 MACCS Health Effects Input Parameter Summary

A summary of the MACCS input parameters related to health effects is provided in Table 3.6-5.

Table 3.6-5: Summary of MACCS input parameters related to health effects

Variable	Description	Value	Source
NUMEFA	Number of Early Fatality Effects	3	Section 3.6.2.1
EFFTHR	Threshold Dose to Target Organ (Gy-Equiv Sv)		
	A-RED MARR	2.32	
	A-LUNGS	13.6	
	A-STOMACH	6.5	
EFFACA	LD50 for Early Fatality Types (Gy-Equiv Sv)		
	A-RED MARR	5.6	
	A-LUNGS	23.5	
	A-STOMACH	12.1	
EFFACB	Shape Factor for Early Fatality Types		
	A-RED MARR	6.1	
	A-LUNGS	9.6	
	A-STOMACH	9.3	
NUMEIN	Number of Early Injury Effects	7	
EISUSC	Susceptible Population Fraction	1 for all health effects	
EINAME	Early Injury Effect Names and Corresponding Organ		
	PRODROMAL VOMIT	A-STOMACH	

Table 3.6-5: Summary of MACCS input parameters related to health effects (continued)

Variable	Description	Value	Source
	DIARRHEA	A-STOMACH	Section 3.6.2.1
	PNEUMONITIS	A-LUNGS	
	SKIN ERYTHRMA	A-SKIN	
	TRANSEPIDERMAL	A-SKIN	
	THYROIDITIS	A-THYROID	
	HYPOTHYROIDISM	A-THYROID	
EITHRE	Early Injury Dose Threshold (Gy-Equiv)		
	PRODROMAL VOMIT	0.5	
	DIARRHEA	1	
	PNEUMONITIS	9.2	
	SKIN ERYTHRMA	3	
	TRANSEPIDERMAL	10	
	THYROIDITIS	40	
	HYPOTHYROIDISM	2	
EIFACA	LD50 For Early Injuries (Gy-Equiv)		
	PRODROMAL VOMIT	2	
	DIARRHEA	3	
	PNEUMONITIS	16.6	
	SKIN ERYTHRMA	6	
	TRANSEPIDERMAL	20	
	THYROIDITIS	240	
	HYPOTHYROIDISM	60	
EIFACB	Shape Factor for Early Injuries		
	PRODROMAL VOMIT	3	
	DIARRHEA	2.5	
	PNEUMONITIS	7.3	
	SKIN ERYTHRMA	5	
	TRANSEPIDERMAL	5	
	THYROIDITIS	2	
	HYPOTHYROIDISM	1.3	
DOSMOD	Dose-Response Model Flag	LNT	Section 3.6.2.2
ACTHRE	Linear Dose-Response Threshold	0	
DOSEFA	Cancer Dose-Response Linear Factors	1 for all organs	
DOSEFB	Cancer Dose-Response Quadratic Factors	0 for all organs	
ACSUSC	Population Susceptible to Cancer	1.0 for all cancers	
NUMACA	Number of Latent Cancer Health Effects	8	
ACNAME	Latent Cancer Effect		
	Cancer Type 1	LEUKEMIA	
	Cancer Type 2	BONE	
	Cancer Type 3	BREAST	
	Cancer Type 4	LUNG	
	Cancer Type 5	THYROID	
	Cancer Type 6	LIVER	
	Cancer Type 7	COLON	
	Cancer Type 8	RESIDUAL	

Table 3.6-5: Summary of MACCS input parameters related to health effects (continued)

Variable	Description	Value	Source
DDTHRE	Threshold for Applying Dose-Dependent Reduction Factor (Sv)	0.2	Section 3.6.2.2
DDREFA	Dose-Dependent Reduction Factor		
	Cancer Type 1	2	
	Cancer Type 2	2	
	Cancer Type 3	1	
	Cancer Type 4	2	
	Cancer Type 5	2	
	Cancer Type 6	2	
	Cancer Type 7	2	
	Cancer Type 8	2	
CIRISK	Lifetime Cancer Injury Risk Factors (1/Sv)		
	Cancer Type 1	0.0113	
	Cancer Type 2	0.000271	
	Cancer Type 3	0.0101	
	Cancer Type 4	0.0208	
	Cancer Type 5	0.00648	
	Cancer Type 6	0.00316	
	Cancer Type 7	0.0378	
	Cancer Type 8	0.169	
CFRISK	Lifetime Cancer Fatality Risk Factors (1/Sv)		
	Cancer Type 1	0.0111	
	Cancer Type 2	0.00019	
	Cancer Type 3	0.00506	
	Cancer Type 4	0.0198	
	Cancer Type 5	0.000648	
	Cancer Type 6	0.003	
	Cancer Type 7	0.0208	
	Cancer Type 8	0.0493	

3.6.4 Identification and Discussion of Uncertainties Related to Health Effects Modeling

There are a numbers of sources of uncertainty in the calculation. These are listed in Table 3.6-6 below, which was generated by reviewing each subsection to identify and characterize the sources of uncertainty. Table 3.6-7 provides a list of potential candidate sensitivity analyses based on a subset of the uncertainties identified in Table 3.6-6.

It is unclear what health consequences, if any, are attributable to very low radiation exposure. Uncertainties in cancer risk estimation are discussed in Section 5.7 of NUREG-1935 (NRC 2012). As discussed in NUREG-1935, "the International Commission on Radiological Protection (ICRP), the National Academy of Sciences, and the United Nations Scientific Committee on the Effects of Atomic Radiation have each indicated that the current scientific evidence is consistent with the hypothesis that an LNT dose-response relationship exists between exposure to ionizing

radiation and the development of cancer in humans." However, in its most recent recommendations (ICRP Report 103), the ICRP warned that "the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided," but that report did not provide a specific dose limit below which quantitative cancer risk estimation should be avoided. A review of ICRP and IAEA literature described in Section 5.7 of NUREG-1935 suggests that doses on the order of a few millirem per year may be considered trivial. In contrast, the Health Physics Society has developed a position paper (HPS 2010) concluding that quantitative estimates of risk should be limited to individuals receiving an annual whole body dose greater than 0.05 Sv (5 rem) or a lifetime dose greater than 0.1 Sv (10 rem). It should be noted that, for much of the long-term phase affected population, intermediate and long-term phase protective actions modeled in MACCS may reduce computed doses to levels below those for which the HPS position statement would recommend performance of quantitative cancer risk estimation. A useful discussion on the attribution of cancer risk may be found in Annex X of Volume 4 of (IAEA 2015). Table X-1 of that annex shows dose ranges and the inferences that may be drawn regarding cancer risks to individuals or populations regarding exposure to different levels of radiation. Because MACCS has the ability to report the size of population exceeding specified dose levels, these qualitative terms are used to help define dose outputs to interpret MACCS results regarding latent fatality risk.

An approach to addressing the uncertainty in stochastic health effects at low doses is to evaluate how the risks would change if computed cancer risks were limited to only higher doses. The MACCS computer code has a capability to model latent-cancer risk subject to annual (DTHANN) and lifetime (DTHLIF) effective dose thresholds. This model is selected by choosing the Annual Threshold dose model on the Dose tab of the Project Properties form in WinMACCS. In WinMACCS a sequence of annual dose threshold values can be entered as a set of Dose Model parameters on the Annual Threshold form. The last value entered applies to all subsequent years. The thresholds, DTHANN and DTHLIF, are always specified on the basis of effective dose even though specific organ doses are used in the dose-response model. If the lifetime threshold DTHLIF is exceeded by the cumulative, effective dose over the exposure period specified in the input, then MACCS uses the sum of all annual, equivalent doses to an organ, without adjustment, to calculate the latent-cancer risk for that organ, the same as it would with a no threshold hypothesis. If an annual threshold DTHANN is exceeded but the lifetime threshold is not, then MACCS includes that annual dose, without adjustment, to estimate a contribution to latent-cancer risk. If the effective dose is less than the annual threshold for that year and the lifetime threshold is not exceeded, then that dose is assumed to have no effect on cancer induction. After MACCS calculates all of the doses that contribute to cancer induction, it applies the factors described in Section 3.6.2 to calculate latent-cancer risks arising from threshold adjusted doses to various organs.

An alternate approach to addressing the uncertainty in stochastic health effects at low doses, including the choice of a potential threshold, would be to sample dose and dose-rate effectiveness factors (DDREF) values from the distribution provided in Table 3.6-3, which was adapted from Table 3 of (Eckerman 2012). As noted by (ICRP 2005), "Unless the existence of a threshold is assumed to be virtually certain, the effect of introducing the uncertain possibility of a

threshold is equivalent to that of an uncertain increase in the value of DDREF, i.e. merely a variation on the result obtained by ignoring the possibility of a threshold". Alternate sources of DDREF distributions identified by (ICRP 2005) include those provided in (NCRP 1997), (EPA 1999b), (Grogan et al. 2001), and (NCI/CDC 2003).

Consistent with the SOARCA analyses and current NRC policy for regulatory applications, the base-case dose-response model used in this analysis to evaluate stochastic effects is the LNT model. Sensitivities of different truncation levels (that limit the quantified health effects to those arising from doses exceeding a predefined threshold) could also be investigated to understand how the risks would change if computed health risks were limited to doses exceeding a predefined threshold. Sensitivity cases may be carried out to better understand the attribution of cancer risk as a function of dose level; until that time, intermediate results, such as the reporting of the peak dose as a function of distance (MACCS Type A output), and the size of the population exceeding specific dose levels (MACCS Type 3 output), may be examined for insights.

Table 3.6-6: Uncertainties related to health effects modeling

3.6.2.1 Acute Health Effects	There is uncertainty in the dose-response function parameters used to estimate acute health effects. Lethal doses for different fatal effects (e.g., hematopoietic syndrome, pulmonary syndrome, gastrointestinal syndrome) are a function both of the dose and the dose rate, as well as the overall health of the exposed individual and the amount of medical care that is available. The potential uncertainty in these parameters has been assessed in NUREG/CR-6545 and distributions to characterize these values are available in Chapter 6 of (Bixler et al. 2013). In addition, the effects of these uncertainties were analyzed in the SOARCA uncertainty analyses (SNL 2016, 2019). In the minute frequency of cases where a non-zero early fatality was calculated, the variables describing the uncertainty in hematopoietic syndrome were found to be important.
3.6.2.2 Stochastic Health Effects	As discussed in (Eckerman 2012), sources of uncertainty in cancer mortality risk coefficients include sampling variations, errors in dosimetry, errors in ascertainment of cause of death, modeling of the dependence on age at exposure and time since exposure, transport of risk estimates from a study group to the U.S. population, extrapolation to low DDREF, and, for high-LET radiation, uncertainty in RBE. Eckerman (2012) provided quantitative estimates of the uncertainty in these mortality risk coefficients. In addition, the effects of uncertainties stemming from DDREF and CFRISK were analyzed in the SOARCA uncertainty analyses (SNL 2016, 2019). The two variables for the “Residual” organ (representative soft tissue/pancreas) were found to be important for latent fatality risk results using the LNT dose-response model.
	There is uncertainty in in the estimates of cancer induction due to low doses and/or dose rates. Some of this uncertainty is reflected in the dose and dose-rate effectiveness factor (DDREF), as discussed in NUREG/CR-6555. Sensitivity studies can be conducted on the parameters used to implement the DDREF to explore the uncertainty in the shape of the dose-response curve. However, to the extent that modeled protective actions are successful at reducing doses, the computed doses in the consequence will be well below the level from which epidemiological data is available (and clearly in the range where a DDREF should be applied). Sensitivity analyses using different truncation levels can demonstrate how many health effects cases arise from different doses/dose rates. Such analyses were conducted as part of the SOARCA uncertainty analyses (SNL 2016, 2019).

Table 3.6-7: Potential sensitivity analyses to address uncertainties related to health effects

Analysis	Objective	MACCS Parameters to be Varied	Expected Results	Implementation Method
HE_1	Examine uncertainty in early health effect parameters	Early fatality parameters set to 10th and 90th percentile value from NUREG/CR-7161	Impact will be noticeable for 1GPT and NE, but not for other cohorts. Early fatality range will be noticeably affected.	Cyclic file set
HE_2	Examine uncertainty associated with low-dose cancer risk estimation	Truncation to background and HPS position statement	Dose truncation will significantly affect cancer risk but no other outputs.	Alternate input decks
HE_3	Examine uncertainty associated with cancer risk estimation	Sample CFRISK values from the distributions provided in Table 3.6-3	Cancer risks expected to be proportional to changes in risk coefficients.	WinMACCS sampling
HE_4	Examine uncertainty associated with the DDREF used for low-dose cancer risk estimation	Sample DDREF values from the distributions provided in Table 3.6-3 or alternate published sources of DDREF distributions	Cancer risks expected to be inversely proportional to changes in DDREF values.	WinMACCS sampling

Table 3.6-8a: Parameters for the 10 mrem annual threshold latent-cancer quantification model

Variable	Description	Value	Source
DOSMOD	Dose-Response Model Flag	AT	Section 3.6.4
DTHNUM	Number of Annual Dose Thresholds	1	
DTHANN	Annual Dose Threshold (Sv/yr)	0.0001	
DTHLIF	Lifetime Dose Threshold (Sv)	-	

Table 3.6-8b: Parameters for the 2010 HPS threshold latent cancer quantification model

Variable	Description	Value	Source
DOSMOD	Dose-Response Model Flag	AT	Section 3.6.4
DTHNUM	Number of Annual Dose Thresholds	1	
DTHANN	Annual Dose Threshold (Sv/yr)	0.05	
DTHLIF	Lifetime Dose Threshold (Sv)	0.10	

3.7 Output Control

Output measures are computed and reported at a variety of hierarchical documentation levels within the L3PRA project. At the highest level are the values reported in the overall project summary (corresponding to, for example, the tables and figures reported in NUREG-1150 or in WASH-1400). These results are, in turn, supported by more detailed results reported in project documentation (corresponding to, for example, the results reported in Chapter 4 of Part 1 of NUREG/CR-4551,Volumes 3-7; e.g., [Breeding et al. 1990]) or in Appendix 6 of WASH-1400 (NRC 1975). These reported results are in turn supported and informed by the frequency-weighting and aggregation steps of the risk integration analyses.

The results presented in Section 4 of this report are those tabulated for use in the risk integration analyses documented in Section 5. This level of documentation contains the more extensive computational results needed to choose metrics to report at higher levels of documentation, and how to report them. At a lower level, the MACCS code is capable of reporting a variety of metrics in its output files. These results are generated by the formulation of an output control statement that specifies which metric to report and how to report it. A number of these output metrics are useful for the interpretation of code results, but are not needed for risk tabulation.

Candidate risk metrics have been identified in the Technical Analysis Approach Plan (Section 1.3). In that document, the candidate metrics were chosen to:

- be consistent with current regulatory applications (i.e., individual risk of early and latent fatalities, collective dose, and economic impacts)
- allow comparison with previous studies (i.e., total early and latent fatalities and early injuries)
- provide additional information to assist in the interpretation of the reported results (e.g., contaminated area)

Individual early fatality risk and individual latent fatality risk are used to support comparison of results to NRC's quantitative health objectives (discussed in [NRC 1986]). These two metrics, supplemented with collective dose and economic impacts, are also used in the NRC regulatory analysis process described in NUREG/BR-0058 (NRC 2004) and NUREG/BR-0184 (NRC 1997). NEPA analyses, as described in Section 7.2 of NUREG-1555 (NRC 2007b), include additional metrics. In addition to these regulatory applications, one of the project aims is to allow comparison to the NUREG-1150 series of studies. That study reported frequency-weighted results for both the total number of early and latent fatalities, as well as the frequency-weighted results for individual risk of early and latent fatality. Earlier studies also included early injuries and incidence of selected cancers. Additional outputs were computed in the L3PRA project to assist in the interpretation of the consequence analysis results. This includes outputs related to the extent of land contamination, which is important for the interpretation of collective measures (e.g., collective dose or health effects and total economic impacts). These measures are integrated over the spatial grid, and the spatial distribution of impacts is therefore an explanatory variable for use in interpreting variations in collective measures. The project computes land contamination in terms of area exceeding defined values for deposition of Cs-

137 (Ci/km^2). In this report, land contamination is reported in terms of area exceeding a deposition level (Ci/km^2 of Cs-137), rather than a dose exceedance level, to facilitate comparison with typically reported metrics for both modeled and measured land contamination. The levels used in this analysis were used in the analyses documented in Enclosure 5 to SECY-12-0157, and are based on the levels used to zone areas following the Chernobyl accident (IAEA 2001). They are expected to be roughly comparable to the area exceeding the long-term protective action levels, which is an indicator of both economic costs and of total population dose. For simplicity, a level of 15 Ci/km^2 (555 kBq/m^2) of Cs-137, corresponding to the zone where relocations were carried out following the Chernobyl accident, is selected as the benchmark deposition level.

The offsite public risk metrics provided in this report include:

- Population-weighted risk to an individual within 1 mile of the site boundary of an early fatality (early fatality risk/yr);
- Population-weighted risk to an individual within 10 miles of the site of a latent cancer fatality (cancer fatality risk/yr)
- Total early fatality risk across the population within 50 and 100[38] miles of the site (fatalities/yr)
- Total latent cancer fatality risk across the population within 50 and 100 miles of the site (fatalities/yr)
- Population dose risk integrated across the population within 50 and 100 miles of the site (person-rem/yr)
- Economic cost risk integrated across the region within 50 and 100 miles of the site ($/yr)
- Intermediate phase population relocation risk integrated across the population within 50 and 100 miles of the site) (person relocated per year)
- Impacted land area (area exceeding 15 Ci/km2 deposition of Cs-137) integrated across the region within 50 and 100 miles of the site (mi2/yr)

The conditional metrics (consequences conditional upon occurrence of each release category) for each of these risk metrics are tabulated in Section 4 of this report. The frequency-weighted risk results corresponding to these conditional results are provided in Section 5. In addition to the values reported for tabulation, additional output can be computed by the MACCS code. Output control statements are used to define the level of information provided in the MACCS output files. Examples of variables that are typically provided in the MACCS output include the weather-averaged consequences for each of the EARLY cohorts and for the CHRONC cohort, and outputs showing the weather-averaged value of parameters such as dose, health effects, or long-term impacts, such as cost or affected area/population at specific radial distances. The output control options are discussed below. The results for these variables are available in the

[38] Early fatalities, if projected to occur at all, are limited to areas well within 50 miles of the site. There is, therefore, no numerical difference between the total number of early fatality cases from 0–50 miles and from 0–100 miles. Because of this, values for early fatalities from 0–100 miles are not reported separately.

detailed MACCS output files. Because the MACCS code is capable of generating very large amounts of output based on the setting of the output control statements (particularly when output controls are set to generate debugging information), the more detailed results that the code is capable of producing are not retained for these analyses, but can be regenerated using the input files documented in this report.

In order to understand the contribution of different weather conditions to the mean results, MACCS allows a table to be generated showing the relative contribution of each of the weather category bins to the mean consequence value by setting the MACCS variable RISCAT to a value of TRUE, provided that weather bin sampling (METCOD=2) has been selected. For the L3PRA analyses, this flag has been set. The relative contribution of each weather bin to the mean value, relative to the frequency of occurrence of that weather bin, provides an indication of how much a particular weather condition contributes to the mean result.

3.7.1 Output Reporting Distances

The distance to which results are computed and reported is a decision to consider in regulatory analysis and other applications. In principle, the computational grid should exceed the distance for the results of interest. Other factors that can be used to evaluate the distance to which the results should be reported include, for example, evaluation of the accuracy of the model results, which may vary as a function of distance from the plant, and averaging interval. To assist in the evaluation of the distance to which results should be reported, and in the interpretation of results that may vary with distance from the plant, results are tabulated in this study for distances of 10, 50, and 100 miles. Distances of 10 and 50 miles are typically used in current regulatory applications, and the MACCS atmospheric dispersion and deposition model has been benchmarked (Molenkamp et al. 2004) to a distance of 100 miles. In addition, output control statements for selected outputs were written for a 500-mile interval to evaluate the extent to which the model results within the 100-mile benchmarked range have either reached an asymptote (for extensive measures integrated over a defined area, such as population dose or economic costs) or dropped to a negligible level for intensive measures, such as individual risks or ground deposition. NUREG-1150, as well as its supporting and supplemental analyses (e.g., [Breeding et al. 1990]; [Mubayi et al. 1995]), have tabulated values out to 1000 miles.[39] The 500-mile outputs computed in this analysis are an intermediate distance between the 1000-mile modeling domain and the 100-mile benchmarked domain. Because the code is limited to reporting only 10 values for several measures of interest, the number of spatial intervals selected was limited to 10. For those measures reported at spatial intervals, output control statements were written for the radial intervals identified in Table 3.7-1.

[39] NUREG-1150 characterizes the distances as “within 50 miles” and “entire site region.” The radius corresponding to the “entire site region” is defined in NUREG-1150, Appendix A, Section A.5.3, as 1000 miles.

Table 3.7-1: Spatial intervals for output control statements

Radial Interval	End of Radial Interval (km)	End of Radial Interval (mi)
4	1.6	1
15	16	10
23	32	20
26	48	30
28	80	50
29	113	70
30	161	100
31	241	150
32	322	200
34	805	500

Depending upon the output measure, the user can generally specify whether a value is to be written at a single radial interval or accumulated over a range of distances. For the L3PRA project, collective values that are integrated over a region have generally been integrated from the point of release to the end of the radial interval. This is discussed in more detail in the following sections.

3.7.2 ATMOS Dispersion Data (Type 0)

MACCS is capable of reporting air and ground concentrations, sigma-y and sigma-z values, arrival time, and time overhead for a user-specified radionuclide for each plume segment at each spatial interval. Because there could be a large combination of plume segments (over 100 for most source terms in this analysis), spatial intervals (35 in this analysis), and radionuclides (69 in this analysis), it is typical to report only a few combinations. For the L3PRA project, Cs-137 was selected as the radionuclide of interest because it drives many consequences and, due to its long half-life, provides a reasonable representation of dispersion because it does not decay significantly during transport. The first plume segment was selected,[40] and the spatial intervals chosen for reporting are those that are given in Table 3.7-1.

3.7.3 Cases of a Given Health Effect (Output Type 1)

MACCS is capable of reporting the number of health effect cases that are estimated to occur within a range of distances. These can include total early fatalities, total cases of specific early injuries, total cancers, or total cancers (either fatal or non-fatal) of a given type. The project computed total early fatalities, total latent cancer fatalities, and a variety of early and latent

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[40] An alternate approach to selecting the plume segment for reporting would be to select the segment with the highest buoyancy flux, which in many cases would be the largest release. This typically would correspond to the MAXRIS plume segment. Selection of the plume segment with the highest buoyancy flux would allow examination of the effect of plume rise on the results.

injuries, including cases of prodromal vomiting and cases of thyroid cancer (fatal and non-fatal). These values are reported as cumulative values from the origin to the end of defined spatial intervals, up to a spatial interval of 100 miles. Output statements were also written to examine the distribution of different cancer types at 50 miles.

3.7.4 Early Fatality Radius (Output Type 2)

This measure reports the greatest distance at which a specified level of early fatality risk is exceeded. For the L3PRA project, information about the size of the region in which early fatalities (if any) are predicted to occur was determined by setting the variable RISTHR (the risk threshold) to the following values: 0., 0.01, 0.05, 0.1, 0.5, 0.9, 0.95, 0.99, and 1. A value of 0 for RISTHR corresponds to the maximum extent (i.e., risk is greater than zero) of the region over which early fatalities are predicted to occur.

3.7.5 Population Exceeding a Dose Threshold (Output Type 3)

This output reports how many people received doses exceeding certain levels. This information can be obtained by requesting the production of the result described below. It is important to remember that this consequence measure is calculated solely on the basis of the dose calculations performed in the EARLY module. There is no provision for examining an analogous result for the CHRONC module, or for determining the number of people whose total dose from both EARLY and CHRONC exceeded a certain level. Also, the generation of this result takes full account of any mitigative action models activated by exceedance of user-specified dose thresholds. For the L3PRA project, this measure was set to identify the number of people exceeding several thresholds for the effective dose L-ICRP60ED, and the acute dose to red bone marrow (A-RED MARR), in order to better understand the distribution of doses received during the early phase. These results are useful in interpreting the health risk values in conjunction with information such as that provided in Volume 4, Annex X of (IAEA 2015). This value is integrated over the entire modeling domain, and cannot be truncated by the specification of a spatial interval. However, it does produce the value on a cohort-specific basis.

3.7.6 Average Individual Risk (Output Type 4)

MACCS allows the reporting of average individual risk, which is obtained by taking the sum of the risk values in all sectors at a given distance and dividing it by the number of sectors. This measure does not account for the population distribution or the likelihood of the wind blowing into different sectors. These values were produces for spatial intervals up to 10 miles.

3.7.7 Population Dose (Output Type 5)

The total long-term population dose to a given organ resulting from the contamination of a specified region can be calculated. The user must supply the name of the target organ as well as the inner and outer spatial intervals of the region of interest. If only the EARLY module is being run, this result reflects only the pathways considered by EARLY. If both EARLY and CHRONC are being run, the population dose from all pathways is included in the calculation. In addition to the direct pathways, the CHRONC pathways include both (1) food and water ingestion doses resulting from material deposited in the region and (2) doses to decontamination workers working in the region. In the L3PRA project, effective population doses (L-ICRP60ED) were output as cumulative values from the origin to the spatial intervals given in Table 3.7-1.

3.7.8 Centerline Dose versus Distance and Centerline Risk versus Distance (Output Types 6 and 7)

These outputs report the centerline dose (Type 6) or centerline risk (Type 7) between a range of distances for the various dose pathways, if the straight-line plume model was chosen (IPLUME=1). Because the L3PRA project used the wind shift option, results of these types are not available.

3.7.9 Population-Weighted Risk (Output Type 8)

The population-weighted health effect risk is obtained by calculating the cases of a health effect in a certain region and then dividing by the total population in the region. The risk presented in this result does not include the societal pathways of (1) ingestion of contaminated food and water or (2) doses to decontamination workers working in the area. Because the code only allows reporting of up to 20 of these outputs, a subset of the health effects used for computing total health effect cases (early fatalities from all causes, cancer fatalities from all cancers) was selected for output. Because these are averaged over the population, values at a single spatial interval cannot be determined by subtraction of individual rings, these values were therefore reported at the spatial intervals identified in Table 3.7-1. The inner distance was set equal to the interval preceding the values in Table 3.7-1, and the outer distance was set equal to the interval specified in Table 3.7-1, up to a distance of 100 miles. Because this measure is used to quantify the safety goal measures for early and latent cancer individual fatality risk, additional spatial intervals were defined to be consistent with the definition of the safety goal measures. Latent cancer fatality risk out to 10 miles was therefore computed. The early fatality safety goal is generally interpreted as the early fatality risk for 1 mile beyond the plant boundary (EAB), which would be 0-1.75 miles). Because the code is currently limited to providing 20 output statements, and because early fatalities are not expected at long distances, individual early fatality risks were only computed out to 50 miles, which is expected to be well beyond the distance where any early fatality risk is expected (see Output Type 2).

3.7.10 Peak Dose at a Distance (Output Type A)

For cases where network evacuation is used with the wind shift option, MACCS allows the reporting of individual doses at each distance over a selected range of distances in a manner analogous to the Type 6 results. There is no dependence on population data. Only direct exposure pathways (i.e., no collective dose pathways, such as food or water ingestion) are considered in the generation of this result. The dose is reported for phantom individuals assumed to be present at all locations. Although these results are calculated on the basis of phantom individuals at each location, these individuals evacuate or relocate according to the cohort description. As a result, these doses are different for different cohorts. The overall weighted sum of results represents the combination of doses calculated by EARLY and CHRONC. Caution should be taken with the use of the overall results obtained by combining the emergency-response cohorts because peak doses for the various cohorts may occur at different angular locations. However, this measure can be used to evaluate how doses drop as a function of distance from the point of release for specific cohorts. In addition, by using information from the complementary cumulative distribution function (CCDF) for this output, a figure showing the likelihood of exceeding specific dose levels as a function of distance from the site, considering the variability in weather and the cohort characteristics, may be produced.

3.7.11 Peak Dose at an (r,θ) Location (Output Type B)

The Type B results are similar to the Type A results, but correspond to the total dose estimated to be incurred by a representative phantom individual assumed to reside at a particular (r,θ) location on the spatial grid. This value was not used in the L3PRA project because the Type A results were determined to be sufficient for output interpretation.

3.7.12 Land Area Exceeding Dose (Output Type C)

This output reports the land area that exceeds a user-specified dose level to an organ. Optionally, dose values for all grid elements for the selected organ are displayed. The generation of this result takes full account of any mitigative action models activated by exceedance of user-specified dose thresholds. This value was used to examine the land area exceeding lifetime effective doses of 1, 10, and 100 rem and acute doses to red bone marrow greater than 1 rad.

3.7.13 Land Area Exceeding Concentration (Output Type D)

This output reports land area that exceeds a user-specified ground concentration level for a specified radionuclide. Optionally, the user can also request ground concentrations and ground-level airborne exposures for every grid element in the MACCS grid. For the L3PRA project, the output statements were written to provide land areas exceeding values of 37 kBq/m^2 (1 Ci/km^2), 185 kBq/m^2 (5 Ci/km^2), 555 kBq/m^2 (15 Ci/km^2), and 1480 kBq/m^2 (40 Ci/km^2) of Cs-137. These values are based on typical levels used to quantify land contamination following the Chernobyl accident (*cf.* Annex I of [IAEA 2001]), and are expected to bracket the range of ground deposition levels where long-term protective actions may be needed.

3.7.14 Population Movement (Output Type E)

Output Type E is a new output type that shows the movement of evacuees. This output was used in the initial development of evacuation models and was turned on to allow examination of the rate at which evacuees were modeled as departing the evacuation zone.

3.7.15 CHRONC Population Dose (Output Type 9)

Output statements for population dose were selected for the L3PRA project as these results are used in the development of cost-benefit analyses. These values are reported as cumulative values from the origin to the spatial intervals given in Table 3.7-1. The CHRONC module calculates the long-term population dose broken down by pathway for a list of organs defined by the user through the EARLY input file (see Section 6.4). For the L3PRA project, the dosimetric quantity selected was L-ICRP60ED, as this is the quantity used in cost-benefit assessments. Each request for the breakdown of the long-term population dose to an organ produces the block of 15 dose results identified below. All of the dose results are reported in person-Sieverts (or person-rem), although the units are listed simply as Sieverts (Sv) (or rem) in the output file.

- TOTAL LONG TERM PATHWAYS DOSE: total long-term population dose from groundshine and resuspension, from the consumption of contaminated food, from the ingestion of contaminated surface water, and from decontamination work.
- LONG TERM DIRECT EXPOSURE PATHWAYS: total long-term population dose to resident population from groundshine and resuspension.
- TOTAL INGESTION PATHWAYS DOSE: total long-term population dose from the consumption of contaminated dairy products, contaminated nondairy products, and contaminated water.
- LONG TERM GROUNDSHINE DOSE: total long-term population dose received by resident population from groundshine.
- LONG TERM RESUSPENSION DOSE: total long-term population dose received by resident population from resuspension.
- POP.-DEPENDENT DECONTAMINATION DOSE: total long-term population dose received from groundshine by workers performing "population-dependent" (nonfarm) decontamination (decontamination workers receive no inhalation dose because they are assumed to wear breathing masks).

- FARM-DEPENDENT DECONTAMINATION DOSE: total long-term population dose received from groundshine by workers performing "farm-dependent" (farmland) decontamination (decontamination workers receive no inhalation dose because they are assumed to wear breathing masks).
- WATER INGESTION DOSE: total long-term population dose from ingestion of contaminated surface water.
- INGESTION OF GRAINS: total long-term population dose resulting from consumption of grains by humans.
- INGESTION OF LEAF VEG: total long-term population dose resulting from consumption of leafy vegetables by humans.
- INGESTION OF ROOT CROPS: total long-term population dose resulting from consumption of root crops by humans.
- INGESTION OF FRUITS: total long-term population dose resulting from consumption of fruits by humans.
- INGESTION OF LEGUMES: total long-term population dose resulting from consumption of legumes by humans.
- INGESTION OF BEEF: total long-term population dose resulting from consumption of beef by humans.
- INGESTION OF MILK: total long-term population dose resulting from consumption of milk by humans.
- INGESTION OF POULTRY: total long-term population dose resulting from consumption of poultry by humans.
- INGESTION OF OTHER MEAT CROPS: total long-term population dose resulting from consumption of other meat crops by humans.

3.7.16 CHRONC: Economic Costs (Output Type 10)

Output statements for economic costs were selected for the project as these results are used in the development of cost-benefit analyses. These values are reported as cumulative values from the origin to the spatial intervals given in Table 3.7-1. Each request for economic results produces the block of 13 economic results described below. All of the economic cost measures in this analysis are reported in 2015 USD.

- TOTAL ECONOMIC COSTS: the sum of population- and farm-dependent costs.
- POP.-DEPENDENT COSTS: the sum of population-dependent decontamination, interdiction, and condemnation costs, as well as emergency-phase and intermediate-phase costs.
- FARM-DEPENDENT COSTS: the sum of farm-dependent decontamination, interdiction, and condemnation costs, as well as milk and crop disposal costs.
- POP.-DEPENDENT DECONTAMINATION COST: nonfarm property (i.e., property associated with residential population) decontamination cost.
- FARM-DEPENDENT DECONTAMINATION COST: farm property decontamination cost.
- POP.-DEPENDENT INTERDICTION COST: depreciation, deterioration, and lost return on investment of nonfarm property during the period it cannot be used (starting with the

emergency phase and ending after the interdiction period ends), plus the cost of population removal (see POPCST).

- FARM-DEPENDENT INTERDICTION COST: depreciation, deterioration, and lost return on investment of farm property during the period it cannot be used during both decontamination and interdiction.
- POP.-DEPENDENT CONDEMNATION COST: compensation paid for permanent loss of nonfarm property, plus the cost of permanent relocation of the population removal.
- FARM-DEPENDENT CONDEMNATION COST: compensation paid for permanent loss of farm property because it could not be returned to production within 8 years of the accident.
- EMERGENCY PHASE COSTS: per-diem costs to compensate people for being away from home due to evacuation and relocation during the emergency phase.
- INTERMEDIATE PHASE COSTS: per-diem costs to compensate people for being away from home due to relocation for the duration of the intermediate phase, if DSCRTI is exceeded.
- MILK DISPOSAL COST: Cost associated with the loss of milk sales from interdiction in the year of the accident. Only 3 months of lost milk sales are computed, as the code assumes that animals may be placed on stored feed to allow resumption of milk production. The cost to actually dispose of the contaminated milk is not included in this output.
- CROP DISPOSAL COST: Cost associated with loss of crop sales from interdiction in the year of the accident. The cost to actually dispose of the contaminated crops is not included in this output.

3.7.17 CHRONC: Action Distance (Output Type 11)

These outputs were selected for the project to aid in the interpretation of how population dose and economic impacts vary with distance from the release point. The long-term protective actions that result from the calculations of the CHRONC module depend on the data supplied by the user. Associated with the long-term actions of decontamination, interdiction, and crop disposal are the maximum distances to which these actions are implemented.

- FARM-DEPENDENT DECONTAMINATION DIST: maximum distance at which farmland decontamination is required.
- POP.-DEPENDENT DECONTAMINATION DIST: maximum distance at which nonfarmland decontamination is required.
- FARM-DEPENDENT INTERDICTION DIST: maximum distance at which farmland decontamination or interdiction is required.
- POP.-DEPENDENT INTERDICTION DIST: maximum distance at which nonfarmland decontamination or interdiction is required.
- FARM-DEPENDENT CONDEMNATION DIST: maximum distance at which farmland condemnation is required.
- POP.-DEPENDENT CONDEMNATION DIST: maximum distance at which nonfarmland condemnation is required.
- MILK DISPOSAL DIST: maximum distance at which the loss of 3 months of milk and dairy product sales is required.

- CROP DISPOSAL DIST: maximum distance at which the loss of 1 year of nonmilk crop sales is required.

3.7.18 CHRONC: Impacted Area/Population (Output Type 12)

These outputs were selected for the project to aid in the interpretation of how population dose and economic impacts vary with distance from the release point, and to assist in understanding what factors are driving the economic costs. Associated with the long-term actions of decontamination, interdiction, condemnation, and crop disposal are the farm areas, nonfarm areas, and populations that are affected by these actions. Each request for impacted farm-area/population results produces the block of eight results identified below. All farm-area results are reported by area and all nonfarm area results are reported by area and number of affected individuals.

- FARM DECONTAMINATION: area within which farmland decontamination was required.
- POP. DECONTAMINATION (INDIVIDUALS): population of areas that required decontamination of nonfarm property.
- POP. DECONTAMINATION (AREA): area that required decontamination of nonfarm property.
- FARM INTERDICTION: farmland area which required either decontamination or interdiction.
- POP. INTERDICTION (INDIVIDUALS): population of areas that required either decontamination or interdiction of nonfarm property.
- POP. INTERDICTION (AREA): area that required either decontamination or interdiction of nonfarm property.
- FARM CONDEMNATION: area within which farmland condemnation was required.
- POP. CONDEMNATION (INDIVIDUALS): population of areas that required condemnation of nonfarm property.
- POP. CONDEMNATION AREA: area that required condemnation of nonfarm property.
- MILK DISPOSAL AREA: affected area requiring the loss of milk and dairy product sales for 3 months.
- CROP DISPOSAL AREA: affected area requiring the loss of nonmilk crop sales for a year.

3.7.19 CHRONC: Individual Food Ingestion Dose at a Distance (Output Type 13)

These outputs were selected for the project to aid in the interpretation of how food ingestion doses, which are subject to the protective action constraints defined in DOSEMILK, DOSEOTHER, and DOSELONG, might vary with distance from the site. The maximum dose is the dose calculated using the food consumption rates specified in the COMIDA2 input file for a representative individual. The projected doses in years 1 through 9 are examined in turn, and the maximum value found is used in generating this result.

3.7.20 CHRONC: Evacuated and Relocated Populations (Output Type 14)

The Type 14 output produces 10 results in the output file as follows:

- Number of evacuees that would not have been impacted by the plume if they had not evacuated

- Number of evacuees that would have been impacted by the plume if they had not evacuated
- Number of relocatees during the emergency phase associated with normal relocation
- Number of relocatees during the emergency phase associated with hotspot relocation
- Number of relocatees during intermediate phase
- Number of relocatees during the long-term phase associated with the first level of decontamination
- Number of relocatees during the long-term phase associated with the second level of decontamination
- Number of relocatees during the long-term phase associated with the third level of decontamination
- Number of relocatees during the long-term phase associated with decontamination plus additional interdiction
- Number of relocatees during the long-term phase whose property is condemned

These outputs were selected for the L3PRA project to assist in evaluating the models . For example, the number of individuals evacuated or relocated during the emergency phase can be compared to the times assumed for evacuation and early phase relocation. These outputs also permit characterizing how the size of the affected population will change as a function of time since the accident.

4 RESULTS

The base-case MACCS analyses were computed using MACCS Version 3.11.2, which includes additional features useful for the L3PRA project. This version includes the ability to vary the length of the emergency phase to account for delayed or prolonged releases; the ability to specify a dose projection period for the early, intermediate, and recovery phases; the ability to combine source terms from multiple sources into a single MACCS run; and additional outputs to aid in evaluating the size of the population that could be affected by different protective actions.

A computational methodology for importing MELCOR source terms, estimating source-term-specific protective action parameters, developing source-term-specific input decks, and executing the analyses was developed for the project. The methodology allowed the source terms to be imported and appropriate input parameters developed in a relatively automated fashion, which reduces the potential for data entry errors, and can increase the traceability of the analysis. The MACCS calculations were performed in individual WinMACCS project files corresponding to the source terms from the Level 2 PRA MELCOR analyses defined in Table 3.1-4. These project files contain the event-specific source terms and the corresponding source-term-specific emergency preparedness values. All project files were developed from a single master project file which defined non-source-term-specific parameter values for all potential cohorts. As discussed in Section 3.4, the number of cohorts actually included for a given source term was accounted for by using the master project file together with an EP-model-specific site file. The project files are grouped into three EP models corresponding to the distance to which evacuation was modeled, and these EP models were further subdivided based on whether a school population between 10-15 miles could be in session given the timing of the event. This resulted in a total of five base-case project files, varying only by the site file used in each (see Table 3.4-5).

For the modeling choices and associated parameters that are generic for all the calculations, project staff reviewed (and updated, as appropriate) all the values in the base project files with those identified in the MACCS Input Summary Tables in the respective subsections of Section 3. The source terms from the MELCOR analysis and the source-term-specific EP values were incorporated separately using parameter update files imported into WinMACCS to update the base-case project files. These source-term-specific EP values were generated by developing a methodology adapted from SNL recommendations. The source term import files and corresponding EP import files were then imported into copies of the base project files, as appropriate, to create the unique project files.

Consistent with the approach in (Breeding et al. 1990) and in (Mubayi et al. 1995), only mean values for each of the source terms were extracted for tabulation in this report. In this summary section, MACCS results have been tabulated for the set of output measures identified in Section 3.7. The mean values reported in these tables represent a weighted average across all weather trials, for an accident at a single unit. Review of intermediate results demonstrates that there can be significant variability in results across weather trials, which is not captured in a mean value. For the outputs selected for tabulation, complementary cumulative distribution function

(CCDF) curves were constructed to display the variability across weather conditions. When CCDF curves for individual source terms are weighted by their respective frequencies, they may be summed to yield a picture of the combined risk, considering both the variability across weather conditions and the relative likelihood of the different release categories.

The results presented in this section were extracted from individual MACCS output files for each release category. Execution of the MACCS code produces results as text and binary files. For the analyses in this report, a Python 2.7 script was developed to extract results from individual MACCS output files into a consistent database format. Use of a script allowed the extraction to be performed more flexibly, as the operation of the script could be controlled by DOS batch files, and the resulting files concatenated to rapidly generate a complete database of different types of MACCS results from all code runs. These concatenated files were then postprocessed using Excel or Python to yield the tables and figures in this report.

Four summary tables (Table 4-1 through Table 4-4) are provided in this section with the mean values for the outputs selected for potential tabulation. The results (for an accident at a single unit) are given conditional on the occurrence of individual release categories (i.e., unweighted), as well as a frequency-weighted sum across all release categories to include consideration of the relative frequency of each type of release. In addition, selected measures from the Level 2 PRA analyses are provided to assist in interpreting results. These include the frequency of occurrence for each release category,[41] the cumulative cesium release fraction, the cumulative iodine release, and the warning time (defined as the elapsed time between the projected general emergency declaration and the time of the first significant release). A more detailed discussion of each result type is included in subsections of this section. These discussions provide relevant intermediate results, such as the contributions from different population cohorts to dose or health risk, or contributions to impacted areas, affected populations, or economic costs from different protective actions. The contributions from different weather bins and individual release categories to the mean values are also provided. Finally, CCDF curves illustrating the variability across weather conditions for different release categories, as well as the composite CCDF representing a frequency-weighted sum of the CCDF curves for individual release categories, are given at the end of each subsection. One item of which the reader should be aware is that certain types of outputs related to populations (i.e., total cases of early or latent fatalities, affected populations, etc.) may report values of less than one person. Values of less than a single person may occur as the result of weighting small populations by low values, usually arising from the combination of low values for the likelihood of being in a specific cohort and relatively infrequent weather conditions. For example, in a hypothetical example of a population of 100 persons, if there is a 0.5% chance of non-evacuation, the size of that

[41] Consistent with (NRC, 2019), individual release categories with a frequency less than 0.1 percent of total release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0×10^{-8}/ry), so as not to over-state the accuracy of the Level 2 PRA model. This artificially raises the risk importance of some very low frequency release categories, but has no significant impact on the risk insights from the study. Note, this approach only applies to this section (Section 4) of the current report; the results provided in Section 5 are based on the actual RCFs for each individual release category, except where reference is specifically made to information obtained from Section 4.

population would be 0.5 persons. If the combination of wind direction and meteorological conditions placed that particular population at risk of elevated exposure for less than 10% of all weather samples, the resulting affected population would be reported as a value of 0.05 persons.

Lastly, note that some figures in Section 4 label the risk metric results in terms of “per reactor year (/ry).” In actuality, these risk metric results are in terms of “per reactor-critical-year (/rcy).”

Table 4-1: Summary of dose measures (mean value across all weather trials)

Release Category	Freq.[1] (/rcy)	Cumul. Cesium Release Frac.	Cumul. Iodine Release Frac.	Warning Time (hr)	Collective Total Effective Dose (person-rem), 0–50 miles	Collective Total Effective Dose (person-rem), 0–100 miles	Population Exceeding Early-Phase Total Effective Dose of 10 rem (persons)[3]	Population Exceeding Early-Phase Acute Red Bone Marrow Dose of 10 rad-eq (persons)[3]
ALL[2] (per rcy)	**6.9E-05**	**7.0E-07**	**9.6E-07**		**9.9E+00**	**2.0E+01**	**2.8E-04**	**9.5E-07**
V-F	1.0E-07	1.3E-01	1.4E-01	2	4.2E+05	1.1E+06	8.6E+02	3.0E+00
V-F-SC	2.0E-07	9.2E-02	1.2E-01	2	3.4E+05	8.2E+05	6.5E+02	2.3E+00
V	7.0E-08	6.4E-04	1.1E-03	2.5	1.4E+04	2.6E+04	4.9E-04	6.1E-06
SGTR-O	7.0E-08	2.5E-01	3.4E-01	4	6.7E+05	2.0E+06	2.6E+02	2.9E-01
SGTR-O-SC	2.0E-07	1.0E-02	9.1E-03	4	6.9E+04	1.4E+05	4.2E-02	7.0E-05
SGTR-C	7.0E-08	1.1E-02	1.2E-02	5	1.1E+05	2.1E+05	2.6E-02	1.2E-03
ISGTR	6.0E-07	9.2E-02	2.3E-01	3	5.7E+05	1.3E+06	6.7E+01	2.8E-01
CIF	7.0E-08	3.4E-02	4.2E-02	18	4.2E+05	8.0E+05	1.3E-01	5.8E-03
CIF-SC	7.0E-08	2.5E-02	3.3E-02	15	3.5E+05	6.6E+05	1.2E-01	5.4E-03
ECF	7.0E-08	1.6E-01	1.5E-01	14	7.3E+05	2.0E+06	2.2E+01	2.0E-02
LCF	2.9E-05	9.9E-03	1.2E-02	52	1.9E+05	3.5E+05	1.4E-04	-
LCF-SC	3.0E-06	1.7E-03	6.0E-04	120	3.0E+04	5.5E+04	-	-
ICF-BURN	9.0E-06	3.2E-02	4.3E-02	25	4.2E+05	8.9E+05	2.8E-04	-
ICF-BURN-SC	2.0E-06	5.9E-05	6.9E-05	25	2.0E+03	3.2E+03	-	-
BMT	8.0E-07	5.4E-05	6.4E-05	230[4]	3.1E+03	5.0E+03	-	-
NOCF	2.4E-05	7.4E-05	8.5E-05	230[4]	3.3E+03	5.0E+03	-	-

Note: Freq.: Frequency; Cumul.: Cumulative; Frac. Fraction

1. *Individual release categories with a frequency less than 0.1 percent of combined release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0E-08/rcy)*
2. *Results are a frequency-weighted sum of all release categories*
3. *Results are integrated across the entire modeling domain*
4. *A warning time of 230 hours indicates that the accident did not progress to a major release, as shown in Table 3.1-4*

Table 4-2: Summary of early health effect measures (mean value across all weather trials)

Release Category	Freq.[1] (/rcy)	Cumul. Cesium Release Frac.	Cumul. Iodine Release Frac.	Warning Time (hr)	Individual Early Fatality Risk, 0–1.8 mi	Early Fatality Cases, 0–50 mi (persons)	Early Injury (Prodromal Vomiting) Cases, 0–50 mi (persons)
ALL[2] (per rcy)	**6.9E-05**	**7.0E-07**	**9.6E-07**		**3.4E-13**	**8.7E-12**	**3.1E-09**
V-F	1.0E-07	1.3E-01	1.4E-01	2	2.1E-06	5.4E-05	9.1E-03
V-F-SC	2.0E-07	9.2E-02	1.2E-01	2	4.0E-07	1.0E-05	7.7E-03
V	7.0E-08	6.4E-04	1.1E-03	2.5	-	-	-
SGTR-O	7.0E-08	2.5E-01	3.4E-01	4	2.5E-07	6.2E-06	1.2E-03
SGTR-O-SC	2.0E-07	1.0E-02	9.1E-03	4	-	-	-
SGTR-C	7.0E-08	1.1E-02	1.2E-02	5	-	-	-
ISGTR	6.0E-07	9.2E-02	2.3E-01	3	5.6E-08	1.4E-06	9.2E-04
CIF	7.0E-08	3.4E-02	4.2E-02	18	-	-	2.2E-08
CIF-SC	7.0E-08	2.5E-02	3.3E-02	15	-	-	-
ECF	7.0E-08	1.6E-01	1.5E-01	14	-	-	1.2E-05
LCF	2.9E-05	9.9E-03	1.2E-02	52	-	-	-
LCF-SC	3.0E-06	1.7E-03	6.0E-04	120	-	-	-
ICF-BURN	9.0E-06	3.2E-02	4.3E-02	25	-	-	-
ICF-BURN-SC	2.0E-06	5.9E-05	6.9E-05	25	-	-	-
BMT	8.0E-07	5.4E-05	6.4E-05	230[3]	-	-	-
NOCF	2.4E-05	7.4E-05	8.5E-05	230[3]	-	-	-

Note: Freq.: Frequency; Cumul.: Cumulative; Frac. Fraction

1. Individual release categories with a frequency less than 0.1 percent of combined release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0E-08/rcy)

2. Results are a frequency-weighted sum of all release categories

3. A warning time of 230 hours indicates that the accident did not progress to a major release, as shown in Table 3.1-4

Table 4-3: Summary of latent health effect measures (mean value across all weather trials)

Release Category	Freq.[1] (/rcy)	Cumul. Cesium Release Frac.	Cumul. Iodine Release Frac.	Warning Time (hr)	Individual Latent Fatality Risk, 0–10 mi	Total Latent Fatality Cases, 0–50 mi (persons)	Total Latent Fatality Cases, 0–100 mi (persons)
ALL[2] (per rcy)	**6.9E-05**	**7.0E-07**	**9.6E-07**		**2.5E-08**	**5.2E-03**	**1.1E-02**
V-F	1.0E-07	1.3E-01	1.4E-01	2	4.6E-04	2.0E+02	5.2E+02
V-F-SC	2.0E-07	9.2E-02	1.2E-01	2	3.4E-04	1.6E+02	3.9E+02
V	7.0E-08	6.4E-04	1.1E-03	2.5	5.4E-05	6.4E+00	1.2E+01
SGTR-O	7.0E-08	2.5E-01	3.4E-01	4	6.6E-04	3.2E+02	1.0E+03
SGTR-O-SC	2.0E-07	1.0E-02	9.1E-03	4	1.2E-04	3.5E+01	7.0E+01
SGTR-C	7.0E-08	1.1E-02	1.2E-02	5	2.1E-04	5.7E+01	1.1E+02
ISGTR	6.0E-07	9.2E-02	2.3E-01	3	8.4E-04	2.8E+02	6.6E+02
CIF	7.0E-08	3.4E-02	4.2E-02	18	7.9E-04	2.2E+02	4.2E+02
CIF-SC	7.0E-08	2.5E-02	3.3E-02	15	6.0E-04	1.8E+02	3.5E+02
ECF	7.0E-08	1.6E-01	1.5E-01	14	8.6E-04	3.7E+02	1.0E+03
LCF	2.9E-05	9.9E-03	1.2E-02	52	6.1E-04	9.8E+01	1.9E+02
LCF-SC	3.0E-06	1.7E-03	6.0E-04	120	1.4E-04	1.5E+01	2.8E+01
ICF-BURN	9.0E-06	3.2E-02	4.3E-02	25	6.7E-04	2.2E+02	4.7E+02
ICF-BURN-SC	2.0E-06	5.9E-05	6.9E-05	25	7.8E-06	7.9E-01	1.3E+00
BMT	8.0E-07	5.4E-05	6.4E-05	230[3]	1.3E-05	1.4E+00	2.3E+00
NOCF	2.4E-05	7.4E-05	8.5E-05	230[3]	1.4E-05	1.3E+00	2.1E+00

Note: Freq.: Frequency; Cumul.: Cumulative; Frac. Fraction

1. Individual release categories with a frequency less than 0.1 percent of combined release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0E-08/rcy)

2. Results are a frequency-weighted sum of all release categories

2. A warning time of 230 hours indicates that the accident did not progress to a major release, as shown in Table 3.1-4

Table 4-4: Summary of land contamination, affected population, and economic cost measures (mean value across all weather trials)

Release Category	Freq.[1] (/rcy)	Cumul. Cesium Release Frac.	Cumul. Iodine Release Frac.	Area exceeding 555 kBq/m^2 Cs-137, 0–50 mi (mi^2)	Area exceeding 555 kBq/m^2 Cs-137, 0–100 mi (mi^2)	Population relocated during intermediate phase, 0–50 mi (persons)	Population relocated during intermediate phase, 0–100 mi (persons)	Total Economic Costs, 0–50 mi (2015$)	Total Economic Costs, 0–100 mi (2015$)
ALL[2] (per rcy)	**6.9E-05**	**7.0E-07**	**9.6E-07**	**4.5E-03**	**4.9E-03**	**5.1E-01**	**5.3E-01**	**8.0E+04**	**9.6E+04**
V-F	1.0E-07	1.3E-01	1.4E-01	5.3E+02	7.6E+02	2.7E+04	3.3E+04	6.0E+09	8.1E+09
V-F-SC	2.0E-07	9.2E-02	1.2E-01	3.7E+02	5.0E+02	1.8E+04	2.3E+04	4.2E+09	5.8E+09
V	7.0E-08	6.4E-04	1.1E-03	5.0E+00	5.0E+00	9.1E+00	9.1E+00	6.3E+07	6.8E+07
SGTR-O	7.0E-08	2.5E-01	3.4E-01	1.2E+03	2.6E+03	7.8E+04	1.2E+05	1.6E+10	2.8E+10
SGTR-O-SC	2.0E-07	1.0E-02	9.1E-03	4.7E+01	4.9E+01	1.1E+03	1.1E+03	4.1E+08	5.8E+08
SGTR-C	7.0E-08	1.1E-02	1.2E-02	1.0E+02	1.0E+02	1.8E+03	1.8E+03	7.4E+08	9.7E+08
ISGTR	6.0E-07	9.2E-02	2.3E-01	7.9E+02	1.1E+03	3.7E+04	4.0E+04	8.4E+09	1.0E+10
CIF	7.0E-08	3.4E-02	4.2E-02	2.8E+02	2.9E+02	1.7E+04	1.7E+04	3.0E+09	3.7E+09
CIF-SC	7.0E-08	2.5E-02	3.3E-02	2.0E+02	2.0E+02	1.6E+04	1.6E+04	2.7E+09	3.1E+09
ECF	7.0E-08	1.6E-01	1.5E-01	9.9E+02	1.5E+03	9.3E+04	1.1E+05	1.5E+10	2.0E+10
LCF	2.9E-05	9.9E-03	1.2E-02	6.3E+01	6.3E+01	4.0E+03	4.0E+03	8.2E+08	1.0E+09
LCF-SC	3.0E-06	1.7E-03	6.0E-04	9.5E+00	9.5E+00	1.6E+01	1.6E+01	8.5E+07	8.7E+07
ICF-BURN	9.0E-06	3.2E-02	4.3E-02	2.1E+02	2.1E+02	3.9E+04	4.0E+04	5.1E+09	6.0E+09
ICF-BURN-SC	2.0E-06	5.9E-05	6.9E-05	5.1E-01	5.1E-01	1.1E-01	1.1E-01	9.1E+06	9.1E+06
BMT	8.0E-07	5.4E-05	6.4E-05	2.0E-01	2.0E-01	4.4E-01	4.4E-01	3.3E+07	3.3E+07
NOCF	2.4E-05	7.4E-05	8.5E-05	5.5E-01	5.5E-01	7.8E-01	7.8E-01	3.4E+07	3.4E+07

Note: Freq.: Frequency; Cumul.: Cumulative; Frac. Fraction

1. Individual release categories with a frequency less than 0.1 percent of combined release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0E-08/rcy)

2. Results are a frequency-weighted sum of all release categories

In addition to the base case results summarized in Tables 4-1 through Table 4-4 and discussed in more detail in sections 4.1 through 4.6, selected sensitivity analyses were run to examine the impact on offsite consequences of certain project assumptions. The three sensitivity cases correspond to sensitivity case ME_2 described in Table 3.2-12 (meteorological sampling), sensitivity case RE_4 (accident truncation time), and sensitivity case HE_2 (use of a dose truncation level for cancer risk estimation corresponding to the 2010 HPS position paper on radiation risk).

The meteorological sampling sensitivity case ME_2 examined the effect of sampling only a subset of weather trials, which has been typical practice for consequence analyses. The weather bins and number of weather trials sampled per bin were based on the INWGHT (SUBSET) column of Table 3.2-8. The number of samples per weather bin used in sensitivity case ME_2 reflect the sampling approach defined in the SOARCA analyses. Execution of this sensitivity case also provided a reference comparison case for running sensitivity cases RE_4 and HE_2 using a smaller weather sample, which provides for increased computational efficiency for these more complex sensitivity analyses.

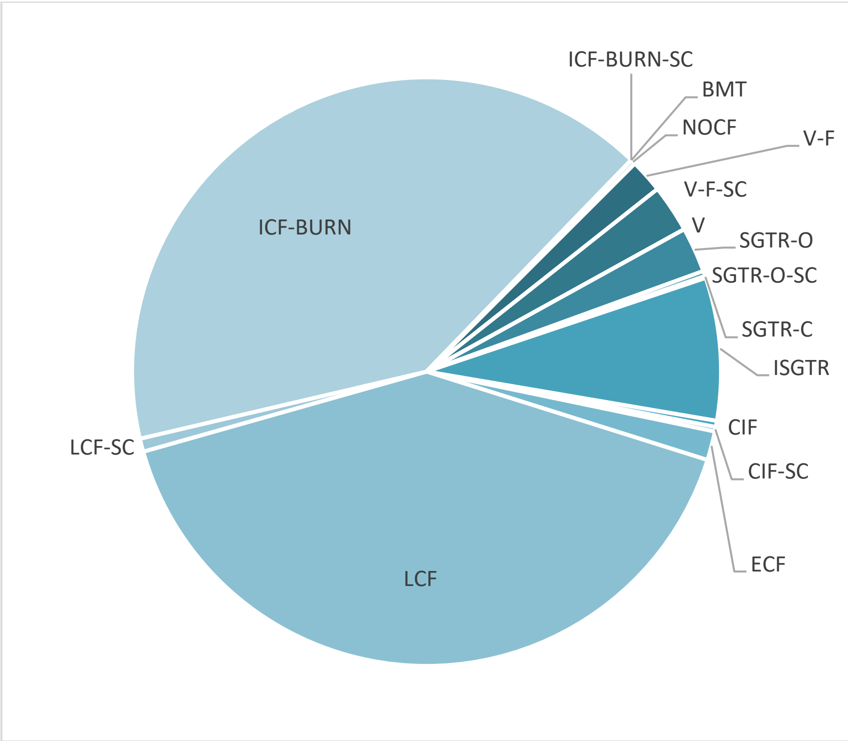
As discussed under “Termination of Radiological Releases” in Appendix D of [NRC 2019], there is significant uncertainty with regard to the severe accident sequence termination time. As such, environmental radiological release results are provided in the Level 2 PRA report for three different accident termination times (36 hours after SAMG entry, 60 hours after SAMG entry, and 7 days after accident initiation). The base case results for the Level 3 PRA (documented in the current report) are based on an accident termination time of 7 days after accident initiation. In order to gain insight into the range of consequence/risk results from different accident termination times, sensitivity case RE_4 allowed examination of the potential impact of terminating radiological releases from all of the representative accident sequences 36 hours after SAMG entry. The conditions for initiating the need for SAMGs are indications that fuel clad has failed and core melt is imminent or occurring, which is indications of readouts of 1200°F on core exit thermocouples. For sensitivity case RE_4, accident releases from MELCOR were truncated 36 hours after the time at which core exit thermocouple temperature was projected to exceed 1200°F. A significant impact of terminating radiological releases 36 hours after SAMG entry is a reduction in the amount of radioactivity released. This is illustrated in Table 4-5 (showing the impact of the accident termination time on the cumulative release fractions for all chemical groups) and Figure 4-1 (showing the impact of accident termination time on the relative contribution of release categories to the frequency-weighted cumulative cesium release fraction). As evident from Table 4-5, the degree of reduction of radioactivity released is a function of both the release category and the chemical group. It can be seen in Table 4-5 that the cumulative cesium release from the LCF and LCF-SC release categories are most affected by the accident termination time, with the total cesium release being reduced by over 99% for the LCF release category. As a result, the relative contribution of release categories to the frequency-weighted cumulative cesium release fraction changes, as seen in Figure 4-1.

Table 4-5: Truncated cumulative release fractions at 36 hours after SAMG entry (RE_4) compared to untruncated cumulative release fractions (ME_2)

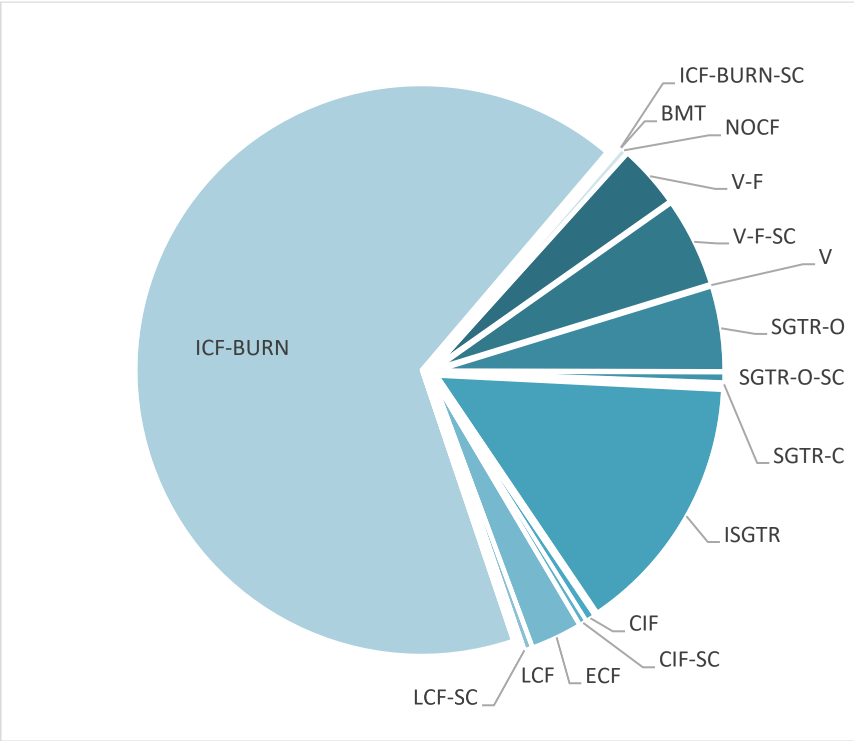
Release Category		Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
V-F	RE_4	7.1E-01	1.3E-01	2.1E-03	1.4E-01	1.3E-01	2.6E-03	3.1E-02	9.3E-05	2.7E-06
	ME_2	8.6E-01	1.3E-01	2.1E-03	1.4E-01	1.3E-01	2.6E-03	3.3E-02	9.3E-05	2.7E-06
	% Truncated	17.4%	0.0%	0.0%	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%
V-F-SC	RE_4	6.5E-01	9.2E-02	1.0E-03	1.2E-01	1.1E-01	1.3E-03	2.3E-02	4.7E-07	3.7E-08
	ME_2	8.6E-01	9.2E-02	1.0E-03	1.2E-01	1.1E-01	1.3E-03	2.3E-02	4.8E-07	4.4E-08
	% Truncated	24.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.1%	15.9%
V	RE_4	9.6E-01	6.4E-04	9.2E-06	1.1E-03	7.5E-04	1.0E-05	1.5E-04	1.5E-07	4.0E-09
	ME_2	9.9E-01	6.4E-04	9.4E-06	1.1E-03	7.6E-04	1.0E-05	1.8E-04	1.5E-07	4.5E-09
	% Truncated	3.0%	0.0%	2.1%	0.0%	1.3%	0.0%	16.7%	0.0%	11.1%
SGTR-O	RE_4	9.0E-01	2.5E-01	2.7E-03	3.4E-01	2.8E-01	3.5E-03	6.0E-02	1.1E-07	1.1E-07
	ME_2	9.2E-01	2.5E-01	2.7E-03	3.4E-01	2.8E-01	3.5E-03	6.3E-02	1.4E-07	1.3E-07
	% Truncated	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	4.8%	21.4%	15.4%
SGTR-O-SC	RE_4	2.8E-01	1.0E-02	3.1E-04	9.1E-03	9.0E-03	1.5E-04	2.4E-03	2.5E-09	2.5E-09
	ME_2	2.8E-01	1.0E-02	3.1E-04	9.1E-03	9.0E-03	1.5E-04	2.4E-03	2.5E-09	2.5E-09
	% Truncated	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SGTR-C	RE_4	1.5E-01	1.1E-02	1.8E-04	1.1E-02	9.6E-03	2.4E-05	2.6E-03	6.1E-08	3.0E-09
	ME_2	2.0E-01	1.1E-02	1.8E-04	1.2E-02	9.6E-03	2.4E-05	3.1E-03	6.8E-08	6.1E-09
	% Truncated	25.0%	0.0%	0.0%	8.3%	0.0%	0.0%	16.1%	10.3%	50.8%
ISGTR	RE_4	8.8E-01	9.0E-02	4.5E-03	2.1E-01	1.9E-01	6.9E-04	1.6E-02	5.8E-08	3.5E-08
	ME_2	9.5E-01	9.2E-02	4.7E-03	2.3E-01	1.9E-01	6.9E-04	2.2E-02	2.4E-07	1.8E-07
	% Truncated	7.4%	2.2%	4.3%	8.7%	0.0%	0.0%	27.3%	75.8%	80.6%
CIF	RE_4	6.1E-01	2.8E-02	1.1E-03	3.3E-02	3.0E-02	7.2E-04	7.0E-03	8.4E-05	2.3E-06
	ME_2	9.8E-01	3.4E-02	1.6E-03	4.2E-02	3.8E-02	7.3E-04	7.2E-02	8.8E-05	3.4E-06
	% Truncated	37.8%	17.6%	31.3%	21.4%	21.1%	1.4%	90.3%	4.5%	32.4%
CIF-SC	RE_4	2.5E-01	2.1E-02	3.3E-04	2.6E-02	2.5E-02	6.3E-04	5.4E-03	1.5E-05	3.8E-07
	ME_2	9.7E-01	2.5E-02	7.1E-04	3.3E-02	2.6E-02	6.3E-04	7.7E-02	1.6E-05	1.5E-06
	% Truncated	74.2%	16.0%	53.5%	21.2%	3.8%	0.0%	93.0%	6.2%	74.7%
ECF	RE_4	8.2E-01	1.5E-01	1.5E-03	1.4E-01	8.0E-02	2.4E-04	2.9E-02	2.9E-06	1.3E-06
	ME_2	9.9E-01	1.6E-01	2.2E-03	1.5E-01	1.3E-01	2.7E-04	2.1E-01	5.6E-06	4.0E-06
	% Truncated	17.2%	6.3%	31.8%	6.7%	38.5%	11.1%	86.2%	48.2%	67.5%

Table 4-5: Truncated cumulative release fractions at 36 hours after SAMG entry (RE_4) compared to untruncated cumulative release fractions (ME_2) (continued)

Release Category		Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
LCF	RE_4	2.5E-03	5.4E-05	1.2E-06	8.3E-05	6.6E-05	6.8E-07	1.1E-05	3.9E-08	1.4E-09
	ME_2	9.1E-01	9.9E-03	3.0E-04	1.2E-02	1.1E-02	6.6E-06	4.0E-02	1.4E-06	5.8E-07
	% Truncated	99.7%	99.5%	99.6%	99.3%	99.4%	89.7%	100.0%	97.2%	99.8%
LCF-SC	RE_4	1.8E-03	4.4E-05	7.5E-07	4.3E-05	3.2E-05	1.7E-07	9.5E-06	6.2E-10	2.9E-10
	ME_2	8.6E-01	1.7E-03	1.1E-04	6.0E-04	3.7E-04	1.8E-07	1.6E-03	2.0E-07	1.8E-07
	% Truncated	99.8%	97.4%	99.3%	92.8%	91.4%	5.6%	99.4%	99.7%	99.8%
ICF-BURN	RE_4	9.4E-01	2.7E-02	1.4E-03	3.7E-02	2.2E-02	5.0E-05	5.8E-03	3.0E-05	2.7E-06
	ME_2	9.9E-01	3.2E-02	2.0E-03	4.3E-02	4.3E-02	6.2E-05	1.4E-01	3.2E-05	4.5E-06
	% Truncated	5.1%	15.6%	30.0%	14.0%	48.8%	19.4%	95.9%	6.2%	40.0%
ICF-BURN-SC	RE_4	6.5E-04	5.9E-05	1.5E-06	6.9E-05	6.6E-05	1.6E-06	1.5E-05	1.4E-07	3.3E-09
	ME_2	6.5E-04	5.9E-05	1.5E-06	6.9E-05	6.6E-05	1.6E-06	1.5E-05	1.4E-07	3.3E-09
	% Truncated	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BMT	RE_4	1.3E-03	4.3E-05	2.3E-06	5.1E-05	4.7E-05	6.6E-07	1.0E-05	1.2E-07	4.3E-09
	ME_2	8.3E-03	5.4E-05	4.0E-06	6.4E-05	9.3E-05	6.7E-07	7.1E-04	1.4E-07	1.1E-08
	% Truncated	84.3%	20.4%	42.5%	20.3%	49.5%	1.5%	98.6%	14.3%	60.9%
NOCF	RE_4	1.2E-03	6.3E-05	1.3E-06	5.1E-05	4.1E-05	3.6E-06	1.5E-05	2.0E-08	1.8E-08
	ME_2	1.0E-02	7.4E-05	2.4E-06	8.5E-05	7.9E-05	3.7E-06	2.0E-04	2.3E-08	2.0E-08
	% Truncated	88.0%	14.9%	45.8%	40.0%	48.1%	2.7%	92.5%	13.0%	10.0%



Base Case



RE_4

Figure 4.1: Relative contribution of release categories to frequency-weighted cumulative cesium release fraction: Base Case vs. RE_4

Sensitivity case HE_2 allowed examination of the cancer risks arising only from moderate or high doses, where the level of uncertainty in cancer risk estimation is less than in the low and very low dose range. This was implemented using a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem). This sensitivity case allowed examination of how much of the projected cancer risk arises from exposures in the low or very low dose range, where cancer risk modeling is more uncertain than in the moderate or high dose range.

In each of the following subsections, the impact of each of these three sensitivity cases on the different consequence measures selected for tabulation is discussed.

4.1 Doses to the Offsite Public

The dosimetric measure selected for risk integration in the L3PRA project includes the collective effective dose from both acute and chronic exposure. Collective effective dose arises from both direct exposure pathways (i.e., groundshine, cloudshine, cloud inhalation, and resuspension inhalation) and collective late-phase indirect exposure pathways (i.e., food and water consumption). Values for the collective effective dose were tabulated at 50 and 100 miles. MACCS results at distances of greater than 100 miles should be viewed with caution because the Gaussian plume segment model in MACCS was not benchmarked in (Molenkamp et al. 2004) at distances of greater than 100 miles, and those values are therefore not tabulated here. However, values out to 500 miles were examined to provide quantitative information on whether the results have either reached an asymptote (indicating that there is no additional contribution to that consequence metric beyond 100 miles) or whether it has dropped to a level that can be considered negligible. This can inform the decision on how to qualitatively characterize results that may need to be truncated at shorter distances because of the uncertainty in model projections at long ranges.

Several intermediate dosimetric results were examined to assist in interpretation of the collective effective dose. These include the size of population exceeding certain early-phase dose levels, the decline in dose with distance from the site for different cohorts, and the probability of exceeding selected dose levels for selected cohorts as a function of distance from the site.

This size of the population receiving moderate or high early-phase doses was generated by the MACCS Type 3 output (Population Exceeding a Dose Threshold). This output was used to identify cohorts with the potential for significant early-phase exposures. This consequence measure is calculated solely on the basis of the dose calculations performed in the EARLY module. There is no provision for examining an analogous result for the CHRONC module, or for determining the number of people whose total dose from both EARLY and CHRONC exceeded a certain level. However, the generation of this result takes full account of any mitigative action models activated by exceedance of user-specified dose thresholds. The values selected for examination include the size of the population in different cohorts receiving high (>100 rem total effective dose or >100 rad-eq acute dose to the red bone marrow) early-phase doses and those receiving moderate (>10 rem total effective dose or >10 rad-eq acute dose to the red bone marrow) early-phase doses. These levels were selected based on the discussion provided in Volume 4, Annex X of (IAEA 2015) (as discussed in Section 3.6), and represent a mean value across all weather trials. Staff examination of these results provides several insights:

1) The potential for moderate or high doses is largely associated with events with large release that bypass containment (interfacing system LOCAs and, to a lesser extent, steam generator tube ruptures).

2) The population receiving high acute doses is very small (at most, less than one person on average),[42] even for the most severe scenarios. The size of the population receiving high total effective doses, or moderate acute doses, is larger, but is still (on average) a very small fraction of the potentially affected population.

3) Moderate-to-high early-phase doses are associated with relatively delayed or slow evacuations.

4) The population receiving a given level of a total effective dose is significantly larger than the population receiving the same level of acute dose, suggesting that total effective doses are higher than acute doses for the same level of exposure. This is indicative of a significant contribution to dose of protracted exposure from internal exposures.

This suggests that only a very small population would be expected to receive high acute doses. Comparison of the results for high versus moderate doses shows a substantial increase in the magnitude of the affected population as the dose levels of interest are reduced from 100 rem to 10 rem, primarily for bypass events with auxiliary building failure. A substantial increase was observed among the general public evacuating cohorts. A larger number of release categories are capable of yielding moderate doses (relative to the release categories yielding high doses), and all represent some form of early containment failure or bypass.

The variation in potential peak doses to members of selected cohorts as a function of distance was examined using the MACCS Type A output (Peak Dose at a Distance). For this output type, there is no dependence on population data. Only direct exposure pathways (i.e., no collective dose pathways such as food or water ingestion) are considered in the generation of this result. The dose is reported for phantom individuals assumed to be present at all locations. Although these results are calculated on the basis of phantom individuals at each location, these individuals evacuate or relocate according to the cohort description. As a result, these doses are different for different cohorts. Several cohorts were selected for detailed examination, as follows:

- the first third of the general public evacuees within 10 miles (1GP1), as an example of a cohort that evacuates promptly and quickly
- the evacuation tail (1GPT), as a cohort that evacuates in a delayed and/or slow fashion
- non-evacuees, who were assumed to be relocated within up to 12 hours after initial plume arrival, to provide a more limiting case for exposure
- the peak late-phase exposures, reflecting individuals who were not subject to relocation or interdiction in the recovery phase, or who were relocated at 10 days after the accident and

[42] Values of less than a single person may occur as the result of weighting small populations by low values, usually arising from the combination of low values for the likelihood of being in a specific cohort and relatively infrequent weather conditions. For example, in a hypothetical example of a population of 100 persons, if there is a 0.5% chance of non-evacuation, and the combination of wind direction and meteorological conditions places that population at risk of elevated exposure for less than 10% of all weather samples, that population would be reported as a value of 0.05 persons.

only returned after decontamination and weathering reduced doses to levels below the habitability criteria of 2 rem in the year of the accident and 500 mrem/yr in subsequent years (this cohort was examined for comparison to early-phase doses)

Inspection of potential doses to selected cohorts revealed a pattern consistent with the observation made from inspection of the Type 3 results; namely, that moderate-to-high doses are associated with relatively delayed or slow evacuations coupled with large, relatively early releases. Cohorts who are able to evacuate both promptly and quickly, such as the first third of the general public evacuees within 5 miles, will receive no dose. Even under a keyhole evacuation scheme, which will reduce the warning time for evacuation by limiting the timing of the evacuation order to within a few hours in advance of a wind shift, the doses are very low, as evident from inspection of the MACCS output results for 1GP1 from 5-10 miles (i.e., the keyhole portion of the evacuation area). In contrast, populations that exhibit a delayed and/or prolonged evacuation, such as the evacuation tail (1GPT), can receive higher doses close to the site. The small fraction of the population within 10 miles that is assumed not to evacuate, but which is assumed to be relocated (if necessary) within up to 12 hours after plume arrival, represents a relatively limiting case for evacuation. By comparison of the results for the evacuation tail to those for the non-evacuating cohort, it may be seen that even for delayed or slow evacuations, release categories with delayed releases (such as the LCF or ICF cases) do not result in significant exposures to evacuating cohorts. This result is in contrast to the non-evacuees who are assumed to be mobilized and relocated only after plume arrival.

Inspection of the peak doses as a function of distance from the site for the non-evacuating cohort and the late-phase cohort (Figure 4.1-1a and Figure 4.1-1b, respectively) shows that high total effective doses are, on average, limited to within 10 miles from the site, even for the non-evacuating cohort who may receive exposures in the most contaminated areas for up to 12 hours. Moderate total effective doses are limited, on average, to within 20 miles of the site. The highest doses are associated with bypass scenarios. Moderate-to-high acute doses are limited to closer distances. In contrast, doses incurred during the recovery phase are low near the site, but do not appreciably decline with distance from the site for the most severe scenarios. This is most likely due to the effect of protective actions, which are assumed to limit individual doses in the intermediate and recovery phases to levels below the habitability criteria, leading to low (<10 rem) lifetime doses. This also results in late-phase dose curves being substantially more clustered, with much less variation in individual doses as a function of distance, than for early-phase dose curves.

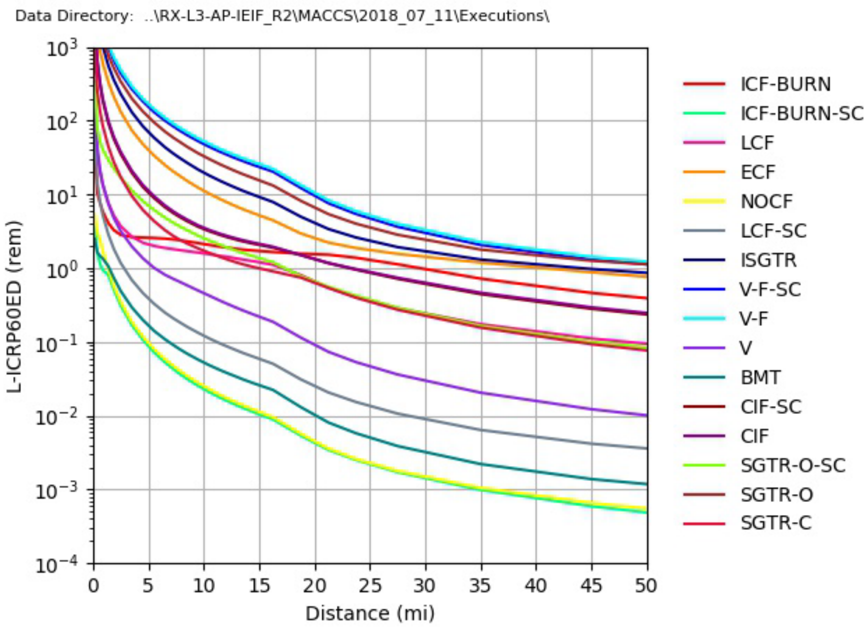


Figure 4.1-1a: Mean value (across all weather trials) of peak total effective dose (rem) from early-phase exposure to the non-evacuating cohort

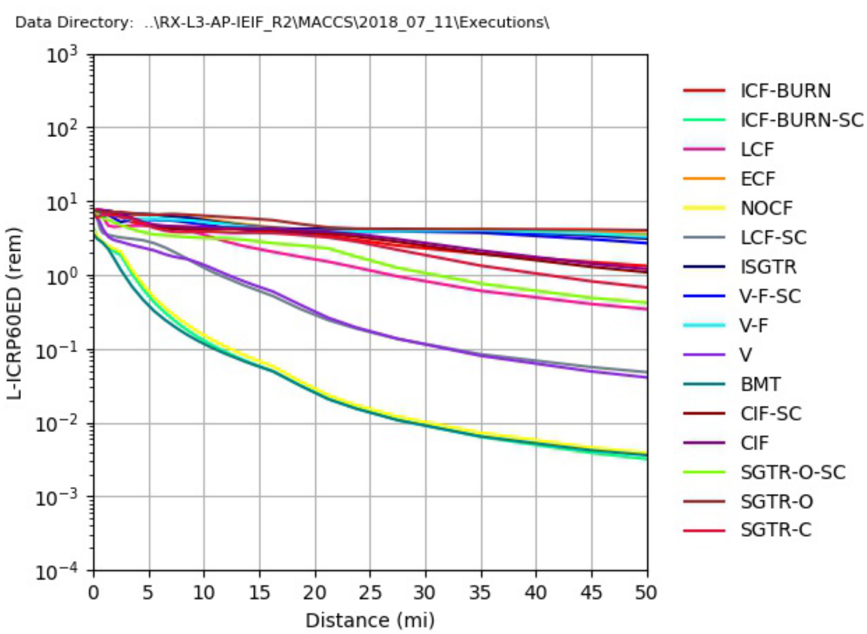


Figure 4.1-1b: Mean value (across all weather trials) of peak total effective eose (rem) from late-phase exposure

A similar conclusion may be drawn from examining the exceedance frequency of a given peak dose level, plotted as a function of distance from the site, for the non-evacuating cohort and for the CHRONC cohort (Figure 4.1-2a and Figure 4.1-2b, respectively). This result shows the likelihood of exceeding a specified dose level at a given distance, given the variability in the weather and the frequency of each individual release category. It is constructed by using the CCDF results reported by MACCS for the Type A output to generate a curve showing the likelihood of exceeding a specified dose level as a function of distance for each individual release category. This gives a curve that is conditional upon the occurrence of the release category. The frequency values for each curve (which reflect variability in meteorological conditions) were then weighted by the frequency of occurrence of each release category, and the resulting weighted curves were then summed to yield the total annual frequency of exceeding the specified dose level as a function of distance from the site, considering the frequency of all modeled release categories. The annual frequency of high (>100 rad-eq) acute red bone marrow doses to the non-evacuating cohort is low and drops off very quickly with distance from the site, dropping below 10^{-9}/rcy at a few miles from the site. The annual frequency of moderate (>10 rad-eq) acute red bone marrow doses is slightly higher, but drops rapidly and is below 10^{-9}/rcy within 20 miles of the site. The inflection point in the frequency reflects the fact that a larger subset of release categories can contribute to the curve at lower dose thresholds, whereas the behavior of the higher consequence, lower probability tail is associated with a smaller set of more consequential release categories.

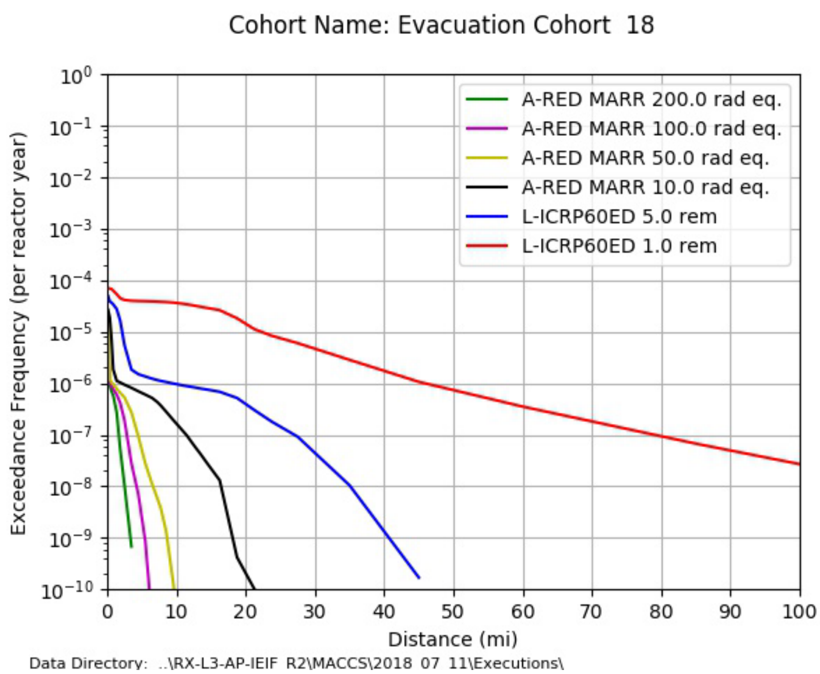


Figure 4.1-2a: Annual frequency of exceeding a specified dose level (rem/rad-eq) from early-phase exposure to the non-evacuating cohort

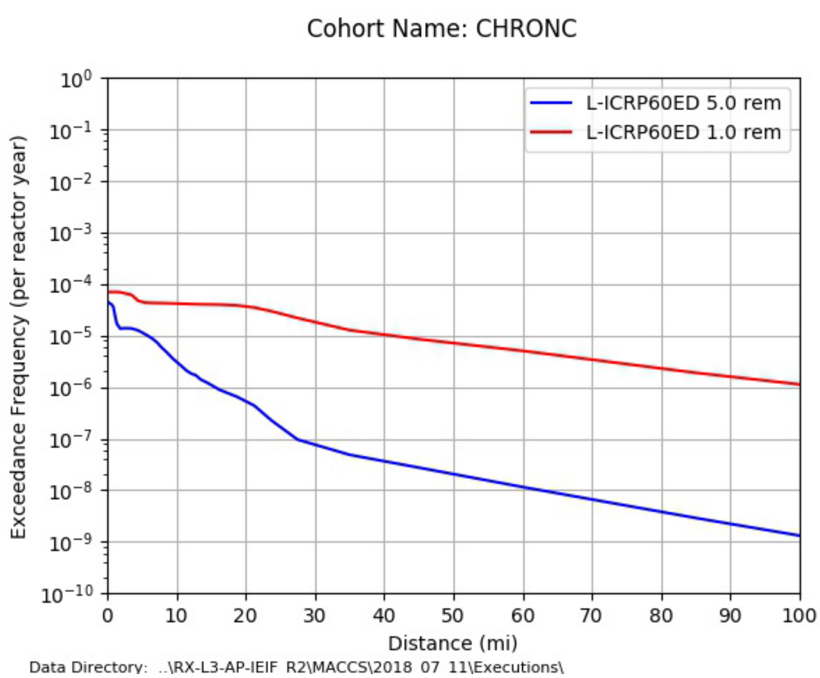


Figure 4.1-2b: Annual frequency of exceeding a specified dose Level (rem) from late-phase exposure

The preceding measures provided an indication of individual doses and how they could be distributed among different cohorts and with distance from the point of release. However, the value selected for tabulation in the L3PRA project is the collective effective dose. The collective effective doses were examined using the MACCS Type 5 output, which provides the total long-term population dose to a given organ resulting from the contamination of a specified region. The results are provided for each early-phase cohort, as well as the late-phase CHRONC cohort. In addition to the direct pathways, the CHRONC pathways include both (1) food and water ingestion doses resulting from material deposited in the region, and (2) doses to decontamination workers working in the region. This output takes full account of the population and its distribution, such that larger population cohorts characterized by lower exposures may exhibit higher overall collective doses. Staff inspection of intermediate results revealed that over 99 percent of the collective effective dose at distances greater than 50 miles is associated with the combination of the late-phase exposures represented by the CHRONC cohort and the early-phase exposures to the non-evacuating individuals beyond the 20-mile evacuation zone. Both of these cohorts are characterized by low (<10 rem) total effective doses to individuals.

The contribution of individual release categories to the mean collective effective dose is shown in Figure 4.1-3. In contrast to the events driving the potential for moderate-to-high doses, which are the lower frequency large releases that bypass containment (interfacing system LOCAs and, to a lesser extent, steam generator tube ruptures), collective effective doses within 50 or 100 miles are dominated by the more likely large releases from late containment failures. This is consistent with the observation that the collective doses are dominated by a combination of the late-phase exposures represented by the CHRONC cohort and the early-phase exposures to the non-evacuating individuals beyond the 20-mile evacuation zone. Evacuation and prompt relocation near the release appears to limit individual exposures, making moderate-to-high individual doses unlikely. As such, the collective doses are dominated by the residual low individual doses. The pattern is similar between the early and late phases, and between 50 and 100 miles (Figure 4.1-4), because all of these cases are dominated by low or very low exposures in regions where protective actions or atmospheric dispersion have reduced the potential individual doses to low or very low levels.

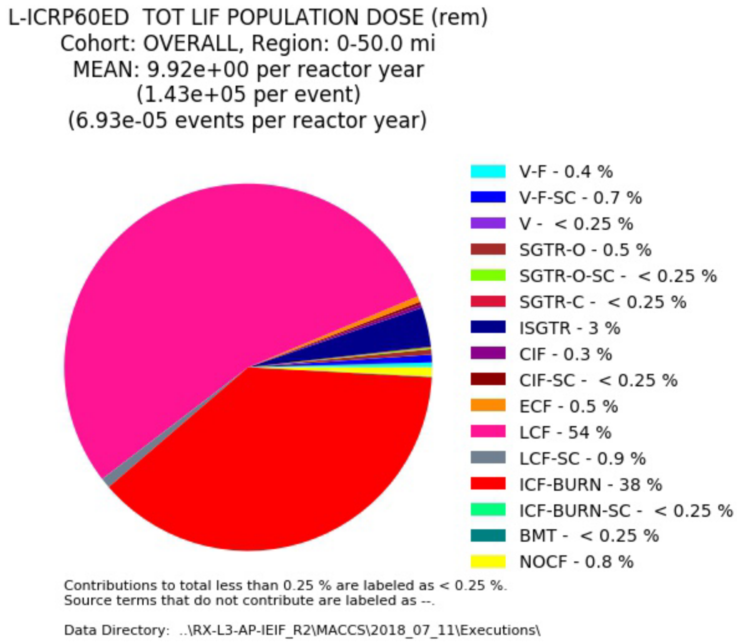


Figure 4.1-3a: Relative contribution of release categories to mean collective effective dose, all cohorts, 0–50 miles

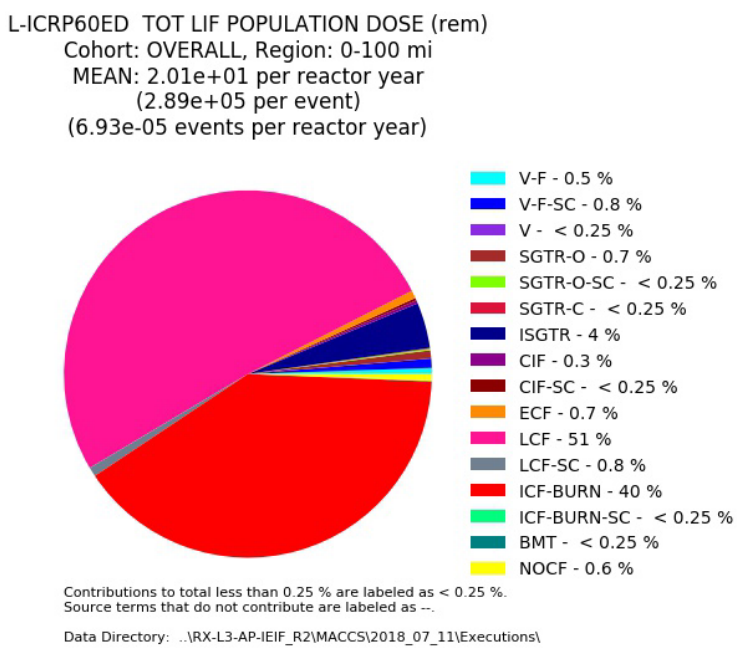
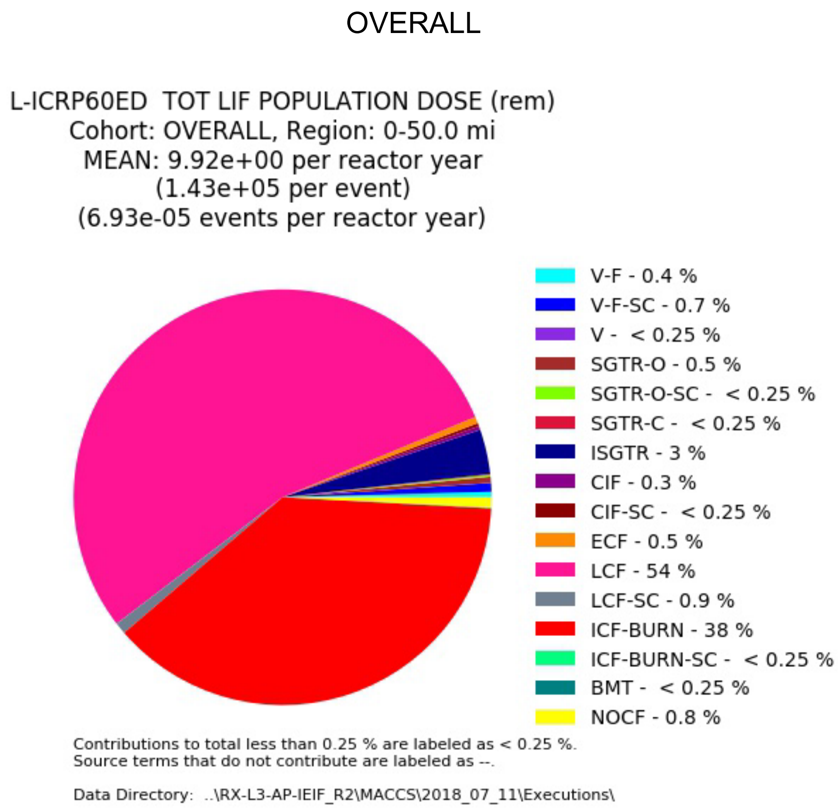


Figure 4.1-3b: Relative contribution of release categories to mean collective effective dose, all cohorts, 0–100 miles



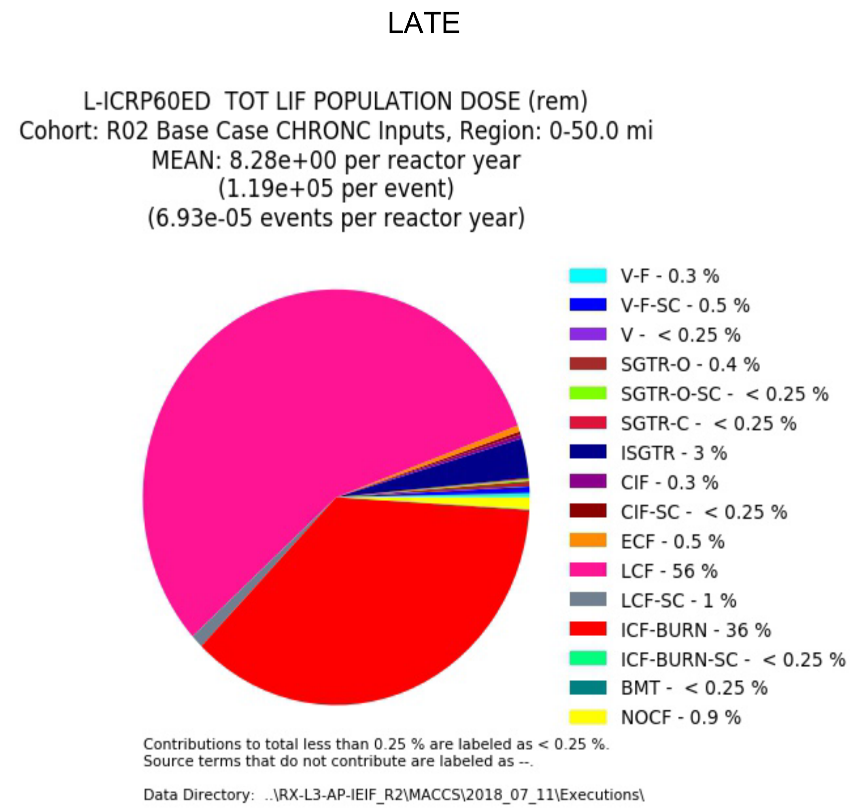


Figure 4.1-4a: Relative contribution of release categories to mean collective total effective dose, all cohorts vs. late phase cohorts only, 0–50 miles

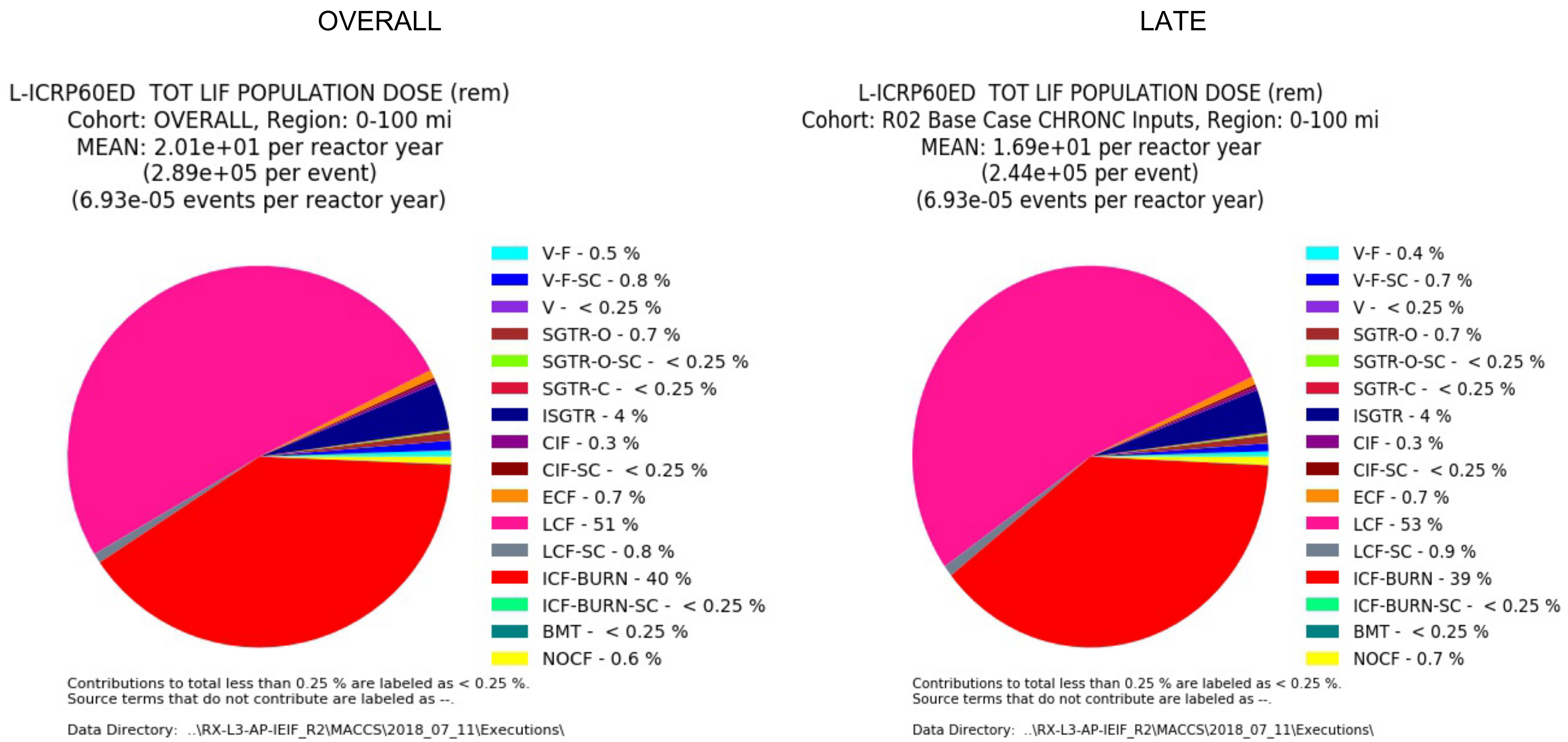


Figure 4.1-4b: Relative contribution of release categories to mean collective total effective dose, all cohorts vs. late phase cohorts only, 0–100 miles

The relative contribution of different weather bins and release categories to the mean population-weighted individual collective dose risk within 50 and 100 miles is shown in Figures 4.1-5 and 4.1-6, respectively. The stacked bar on the left shows the relative contribution to the mean for a particular weather bin from each release category. The solid blue bar to the right shows the relative frequency of the weather bin. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. These figures suggest that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value. This suggests that this result may not be particularly sensitive to the selection of alternate weather years, because there do not appear to be weather conditions that contribute disproportionately to the mean value.

The discussion above has focused on the mean values. The complementary cumulative distribution function provides information on the variability of the results as a result of weather conditions and different release categories. The CCDF curves for collective effective dose, for 0–50 miles and 0–100 miles, are shown in Figures 4.1-7 and 4.1-8, respectively. Release categories LCF and ICF-BURN appear to be the main contributors to collective effective dose, particularly at the higher frequencies. This is consistent with the observations drawn from Figure 4.1-3.

In summary, it appears that exposures resulting in moderate-to-high doses are associated with low frequency large releases that bypass containment and are limited to areas close to the site and to populations that are slow to mobilize and depart. However, the majority of collective population dose is due to the relatively higher frequency large releases that result from eventual containment failure. This dose primarily arises from low (<10 rem) exposures to (1) populations who were not subject to evacuation in the early phase (i.e., residing >20 mi from the plant), (2) those who were not subject to relocation or interdiction in the recovery phase, or (3) those who were relocated at 10 days after the accident and only returned after decontamination and weathering reduced doses to levels below the habitability criteria of 2 rem in the year of the accident and 500 mrem/yr in subsequent years.

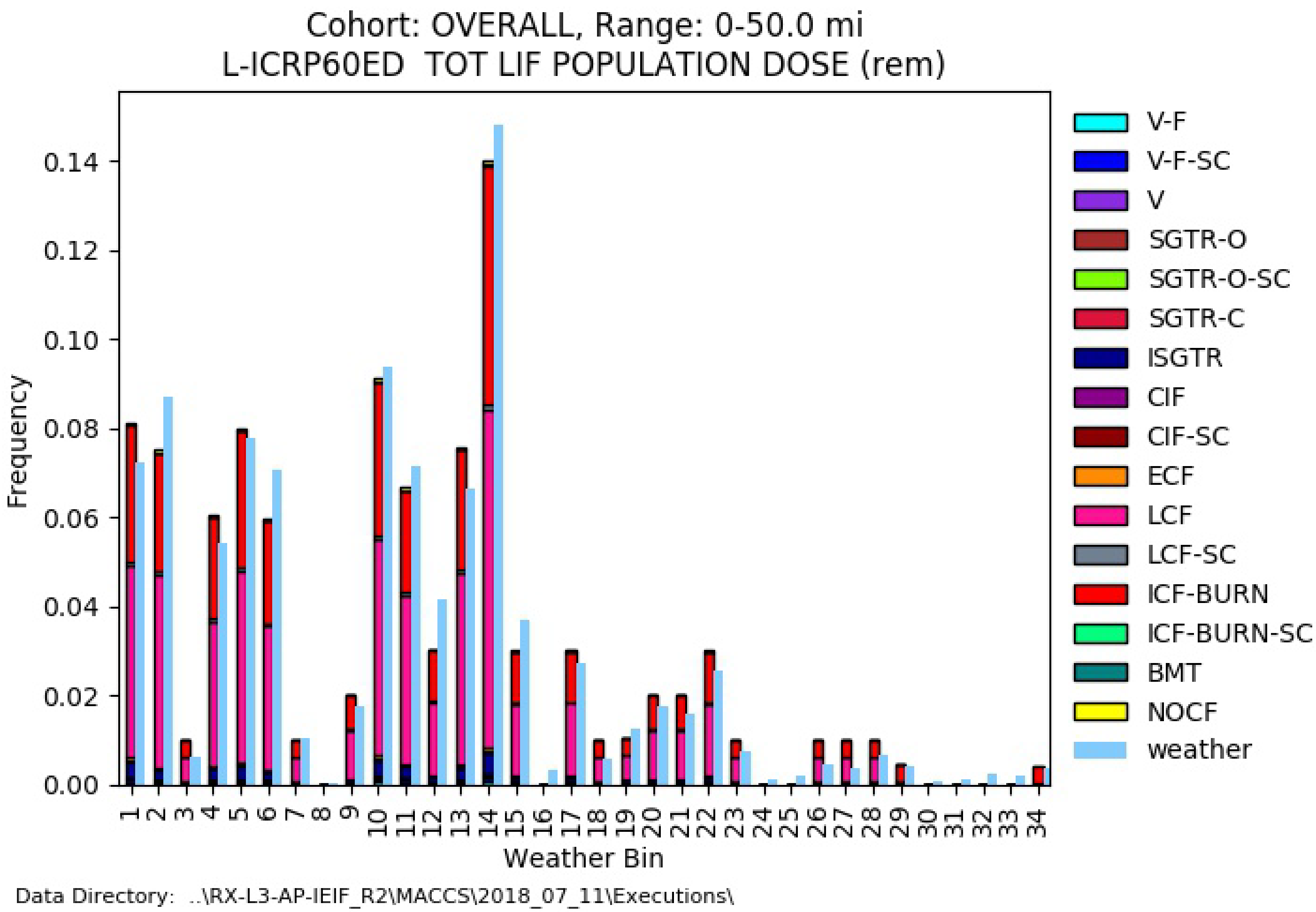


Figure 4.1-5: Relative contribution of weather bins and release categories to mean (across all weather trials) collective total effective dose within 50 miles

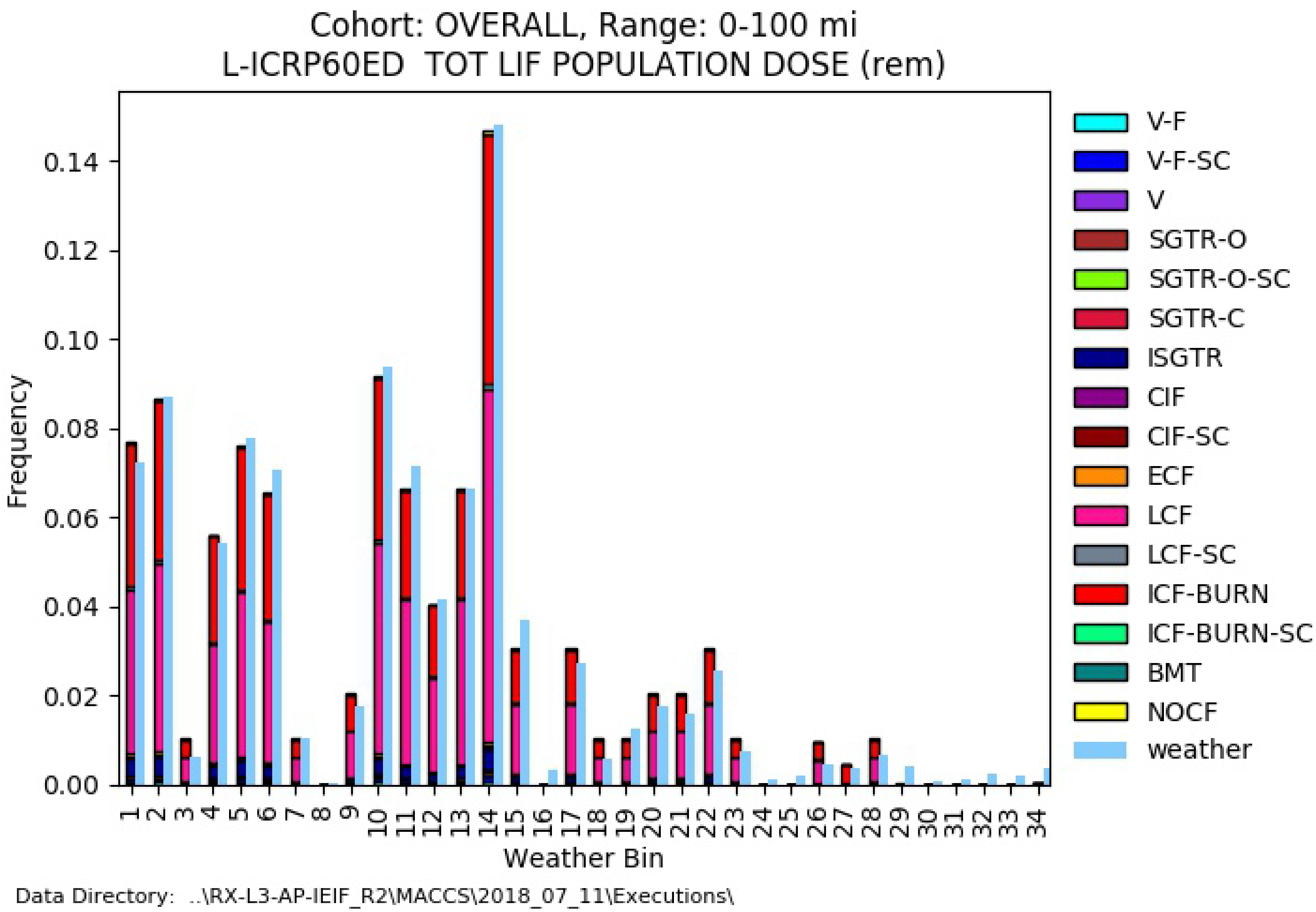


Figure 4.1-6: Relative contribution of weather bins and release categories to mean (across all weather trials) collective total effective dose within 100 miles

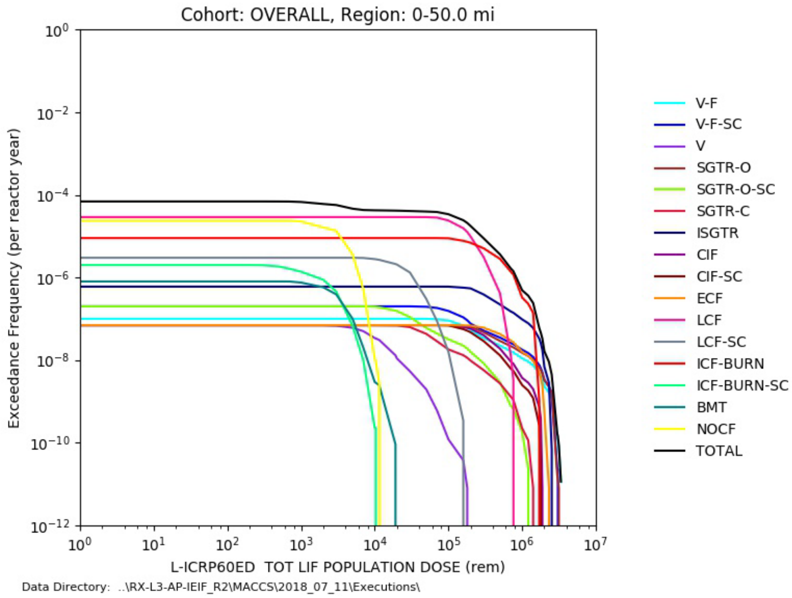


Figure 4.1-7: Complementary cumulative distribution function of collective total effective dose, 0–50 miles (person-rem)

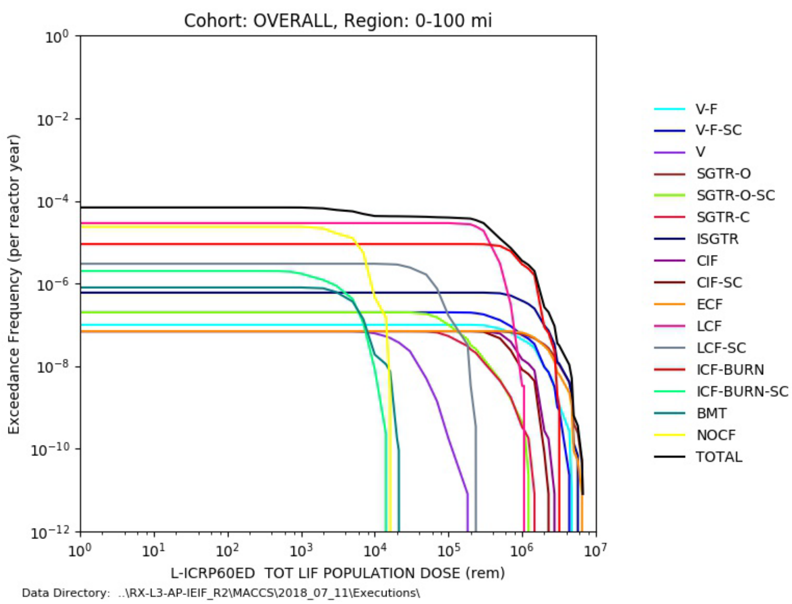


Figure 4.1-8: Complementary cumulative distribution function of collective total effective dose, 0–100 miles (person-rem)

4.1.1 Sensitivity Cases

4.1.1.1 *Meteorological Sampling*

The effect of sampling only a subset of the meteorological data on the collective effective dose within 50 and 100 miles is demonstrated in Tables 4.1-1 and 4.1-2. It is evident from inspection of these results that differences resulting from sampling a representative subset of weather trials as opposed to sampling all 8760 hourly observations are generally less than a few percent.

Table 4.1-1: Mean (Across all weather trials) collective total effective dose (person-rem), 0–50 miles: ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**9.9E+00**	**9.8E+00**	**0.985**
V-F	1.0E-07	4.2E+05	4.2E+05	1.000
V-F-SC	2.0E-07	3.4E+05	3.4E+05	0.994
V	7.0E-08	1.4E+04	1.4E+04	1.007
SGTR-O	7.0E-08	6.7E+05	6.6E+05	0.988
SGTR-O-SC	2.0E-07	6.9E+04	7.0E+04	1.015
SGTR-C	7.0E-08	1.1E+05	1.1E+05	1.009
ISGTR	6.0E-07	5.7E+05	5.7E+05	0.995
CIF	7.0E-08	4.2E+05	4.2E+05	0.988
CIF-SC	7.0E-08	3.5E+05	3.4E+05	0.994
ECF	7.0E-08	7.3E+05	7.4E+05	1.007
LCF	2.9E-05	1.9E+05	1.8E+05	0.978
LCF-SC	3.0E-06	3.0E+04	3.0E+04	1.003
ICF-BURN	9.0E-06	4.2E+05	4.1E+05	0.993
ICF-BURN-SC	2.0E-06	2.0E+03	2.0E+03	1.000
BMT	8.0E-07	3.1E+03	3.2E+03	1.013
NOCF	2.4E-05	3.3E+03	3.2E+03	0.997

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs

Table 4.1-2: Mean (Across all weather trials) collective total effective dose (person-rem), 0–100 miles: ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case
ALL[1] (per rcy)	**6.9E-05**	**2.0E+01**	**2.0E+01**	**0.988**
V-F	1.0E-07	1.1E+06	1.1E+06	0.991
V-F-SC	2.0E-07	8.2E+05	8.3E+05	1.015
V	7.0E-08	2.6E+04	2.6E+04	1.000
SGTR-O	7.0E-08	2.0E+06	2.0E+06	1.000
SGTR-O-SC	2.0E-07	1.4E+05	1.4E+05	1.014
SGTR-C	7.0E-08	2.1E+05	2.1E+05	1.010
ISGTR	6.0E-07	1.3E+06	1.4E+06	1.007
CIF	7.0E-08	8.0E+05	7.9E+05	0.993
CIF-SC	7.0E-08	6.6E+05	6.6E+05	0.994
ECF	7.0E-08	2.0E+06	2.0E+06	1.000
LCF	2.9E-05	3.5E+05	3.5E+05	0.989
LCF-SC	3.0E-06	5.5E+04	5.5E+04	1.000
ICF-BURN	9.0E-06	8.9E+05	8.8E+05	0.984
ICF-BURN-SC	2.0E-06	3.2E+03	3.2E+03	1.003
BMT	8.0E-07	5.0E+03	5.0E+03	0.998
NOCF	2.4E-05	5.0E+03	5.0E+03	0.998

1. Results are a frequency-weighted sum of all release categories

The effect of sampling only a subset of the meteorological data on the population exceeding an early-phase total effective dose of 10 rem is shown in Table 4.1-3. The effect of sampling only a subset of the meteorological data on the population exceeding an early-phase acute red bone marrow dose of 10 rad-eq (persons) is shown in Table 4.1-4. The sensitivity of these metrics, which represent the small subset of the population that may receive elevated doses, is greater than the sensitivity of the collective effective dose to weather sampling. The overall frequency weighted results can vary by on the order of 10%, and the effect on individual release categories can vary between a factor of 0.4 to 1.2.

Table 4.1-3: Mean (across all weather trials) population exceeding early-phase total effective dose of 10 rem (persons): ME_2

Release Category	Frequency (/rcy)	Base Case[2]	ME_2[2]	Fraction of Base Case[3]
ALL[2] (per rcy)	**6.9E-05**	**2.8E-04**	**3.1E-04**	**1.117**
V-F	1.0E-07	8.6E+02	8.9E+02	1.037
V-F-SC	2.0E-07	6.5E+02	7.7E+02	1.184
V	7.0E-08	4.9E-04	2.0E-04	0.414
SGTR-O	7.0E-08	2.6E+02	3.1E+02	1.178
SGTR-O-SC	2.0E-07	4.2E-02	3.8E-02	0.899
SGTR-C	7.0E-08	2.6E-02	2.1E-02	0.826
ISGTR	6.0E-07	6.7E+01	6.9E+01	1.044
CIF	7.0E-08	1.3E-01	1.2E-01	0.916
CIF-SC	7.0E-08	1.2E-01	1.0E-01	0.904
ECF	7.0E-08	2.2E+01	2.2E+01	0.995
LCF	2.9E-05	1.4E-04	1.6E-04	1.207
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	2.8E-04	2.6E-04	0.936
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories
2. Results are integrated across the entire modeling domain
3. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.1-4: Mean (across all weather trials) population exceeding early-phase acute red bone marrow dose of 10 rad-eq (persons): ME_2

Release Category	Frequency (/rcy)	Base Case[2]	ME_2[2]	Fraction of Base Case[3]
ALL[1] (per rcy)	**6.9E-05**	**9.5E-07**	**8.6E-07**	**0.905**
V-F	1.0E-07	3.0E+00	2.9E+00	0.967
V-F-SC	2.0E-07	2.3E+00	1.9E+00	0.826
V	7.0E-08	6.1E-06	-	-
SGTR-O	7.0E-08	2.9E-01	2.7E-01	0.927
SGTR-O-SC	2.0E-07	7.0E-05	-	-
SGTR-C	7.0E-08	1.2E-03	1.4E-03	1.129
ISGTR	6.0E-07	2.8E-01	2.8E-01	1.011
CIF	7.0E-08	5.8E-03	6.3E-03	1.097
CIF-SC	7.0E-08	5.4E-03	6.0E-03	1.103
ECF	7.0E-08	2.0E-02	1.7E-02	0.850
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories
2. Results are integrated across the entire modeling domain
3. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.1.1.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on the collective effective dose within 50 and 100 miles is demonstrated in Tables 4.1-5 and 4.1-6. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

The effect of terminating the release is a reduction on the collective total effective dose. On a frequency-weighted basis, the reduction is approximately a factor of four. It can be seen that some release categories (such as ISLOCA or SGTR release categories) are relatively unaffected with a reduction on the order of a few percent, whereas other release categories (such as the late containment failure (LCF) release category) are reduced by almost 99%.

The differential impact of the accident termination time on the relative contribution of release categories to the overall mean collective effective dose within 50 and 100 miles is illustrated in Figures 4.1-9 and 4.1-10, respectively. The frequency weighted reduction in the collective effective dose is a combination of the much lower conditional consequences for the LCF release

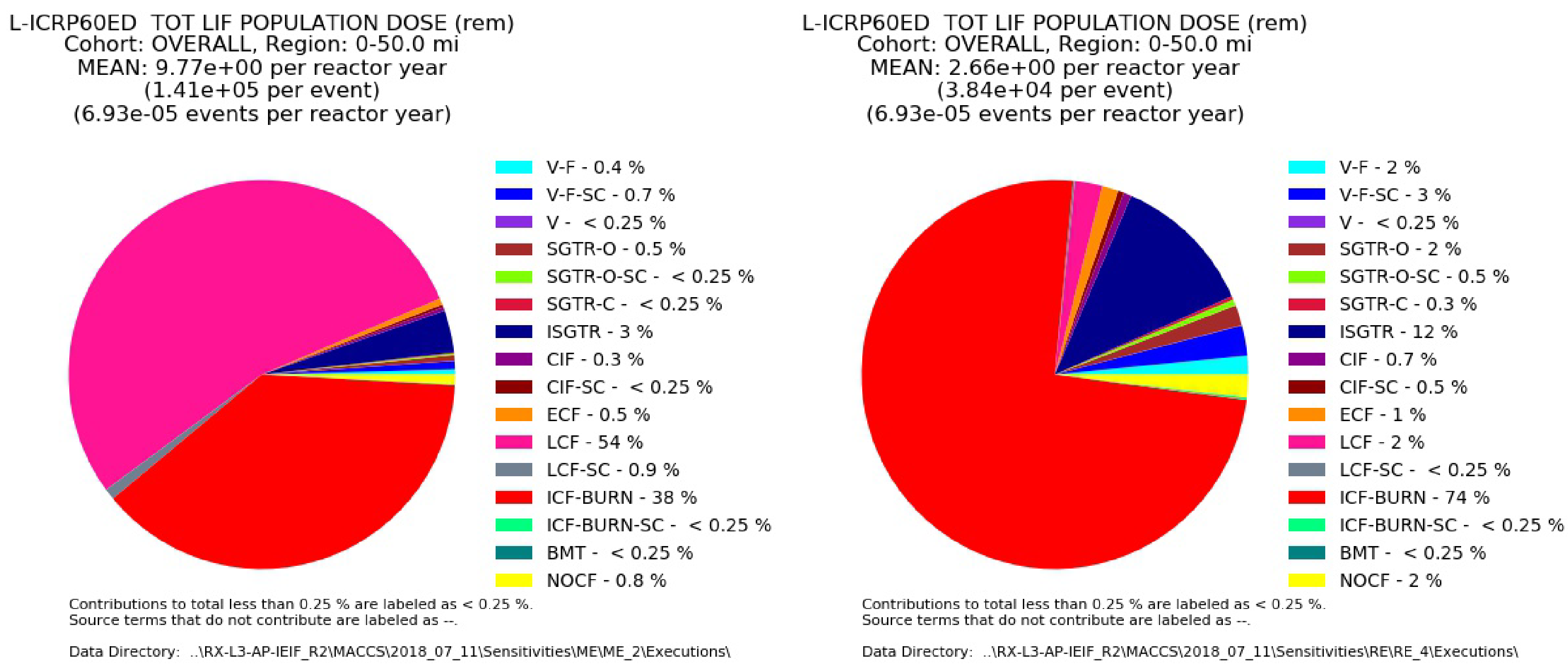
category with a significant reduction in the conditional consequences for the ICF-BURN release category. The relative contribution of release categories to the mean collective effective dose is similar to the relative contribution of release categories to the cumulative cesium release shown in Figure 4-1, with the ICF-BURN and ISGTR release categories increasing in relative importance and the LCF release category comprising a much smaller contributor.

Table 4.1-5: Mean (across all weather trials) collective total effective dose (person-rem), 0–50 miles: RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**9.8E+00**	**2.7E+00**	**0.272**
V-F	1.0E-07	4.2E+05	4.1E+05	0.990
V-F-SC	2.0E-07	3.4E+05	3.3E+05	0.994
V	7.0E-08	1.4E+04	1.4E+04	0.993
SGTR-O	7.0E-08	6.6E+05	6.4E+05	0.971
SGTR-O-SC	2.0E-07	7.0E+04	7.0E+04	1.000
SGTR-C	7.0E-08	1.1E+05	1.1E+05	0.956
ISGTR	6.0E-07	5.7E+05	5.3E+05	0.930
CIF	7.0E-08	4.2E+05	2.5E+05	0.603
CIF-SC	7.0E-08	3.4E+05	1.8E+05	0.536
ECF	7.0E-08	7.4E+05	5.2E+05	0.701
LCF	2.9E-05	1.8E+05	2.1E+03	0.012
LCF-SC	3.0E-06	3.0E+04	1.5E+03	0.050
ICF-BURN	9.0E-06	4.1E+05	2.2E+05	0.531
ICF-BURN-SC	2.0E-06	2.0E+03	2.0E+03	1.000
BMT	8.0E-07	3.2E+03	1.5E+03	0.484
NOCF	2.4E-05	3.2E+03	2.1E+03	0.651

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2) RE_4

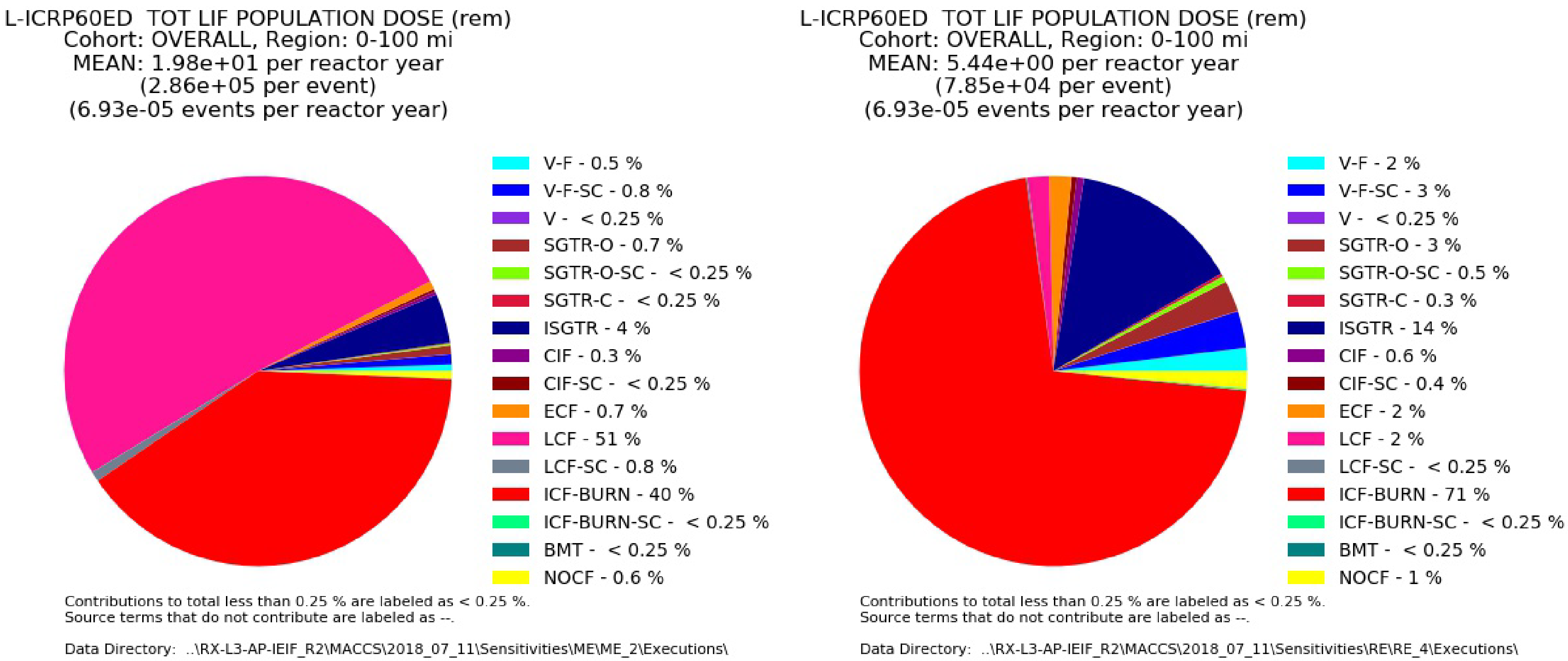
Figure 4.1-9: Relative contribution of release categories to overall mean collective total effective dose, 0–50 miles: RE_4

Table 4.1-6: Mean (across all weather trials) collective total effective dose (person-rem), 0–100 miles: RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**2.0E+01**	**5.4E+00**	**0.275**
V-F	1.0E-07	1.1E+06	1.0E+06	0.990
V-F-SC	2.0E-07	8.2E+05	8.3E+05	0.996
V	7.0E-08	2.6E+04	2.6E+04	0.992
SGTR-O	7.0E-08	2.0E+06	2.0E+06	0.980
SGTR-O-SC	2.0E-07	1.4E+05	1.4E+05	1.000
SGTR-C	7.0E-08	2.1E+05	2.0E+05	0.953
ISGTR	6.0E-07	1.3E+06	1.3E+06	0.948
CIF	7.0E-08	8.0E+05	4.7E+05	0.597
CIF-SC	7.0E-08	6.6E+05	3.5E+05	0.528
ECF	7.0E-08	2.0E+06	1.4E+06	0.722
LCF	2.9E-05	3.5E+05	3.4E+03	0.010
LCF-SC	3.0E-06	5.5E+04	2.5E+03	0.044
ICF-BURN	9.0E-06	8.9E+05	4.3E+05	0.490
ICF-BURN-SC	2.0E-06	3.2E+03	3.2E+03	1.000
BMT	8.0E-07	5.0E+03	2.4E+03	0.474
NOCF	2.4E-05	5.0E+03	3.3E+03	0.659

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2) RE_4

Figure 4.1-10: Relative contribution of release categories to overall mean collective effective dose, 0–100 miles: RE_4

The effect of terminating the accident release 36 hours after SAMG entry on the size of the population receiving elevated doses is demonstrated in Tables 4.1-7 and 4.1-8. It can be seen that the effect of terminating the release 36 hours after SAMG entry has minimal impacts, suggesting the potential for elevated doses is largely attributable to that the portion of the release within 36 hours after SAMG entry.

Table 4.1-7: Mean (across all weather trials) population exceeding early-phase total effective dose of 10 rem (persons): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2) [2]	RE_4[2]	Fraction of Reference Case[3]
ALL[1] (per rcy)	**6.9E-05**	**3.1E-04**	**3.1E-04**	**0.999**
V-F	1.0E-07	8.9E+02	8.9E+02	1.000
V-F-SC	2.0E-07	7.7E+02	7.7E+02	1.000
V	7.0E-08	2.0E-04	2.0E-04	1.000
SGTR-O	7.0E-08	3.1E+02	3.1E+02	1.000
SGTR-O-SC	2.0E-07	3.8E-02	3.8E-02	1.000
SGTR-C	7.0E-08	2.1E-02	2.1E-02	1.000
ISGTR	6.0E-07	6.9E+01	6.9E+01	0.994
CIF	7.0E-08	1.2E-01	1.2E-01	1.000
CIF-SC	7.0E-08	1.0E-01	1.0E-01	1.000
ECF	7.0E-08	2.2E+01	2.2E+01	1.000
LCF	2.9E-05	1.6E-04	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	2.6E-04	2.6E-04	1.000
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories
2. Results are integrated across the entire modeling domain
3. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.1-8: Mean (across all weather trials) population exceeding early-phase acute red bone marrow dose of 10 rad-eq (persons): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2) [2]	RE_4[2]	Fraction of Reference Case[3]
ALL[1] (per rcy)	**6.9E-05**	**8.6E-07**	**8.6E-07**	**1.000**
V-F	1.0E-07	2.9E+00	2.9E+00	1.000
V-F-SC	2.0E-07	1.9E+00	1.9E+00	1.000
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	2.7E-01	2.7E-01	1.000
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	1.4E-03	1.4E-03	1.000
ISGTR	6.0E-07	2.8E-01	2.8E-01	1.000
CIF	7.0E-08	6.3E-03	6.3E-03	1.000
CIF-SC	7.0E-08	6.0E-03	6.0E-03	1.000
ECF	7.0E-08	1.7E-02	1.7E-02	1.000
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. *Results are a frequency-weighted sum of all release categories*
2. *Results are integrated across the entire modeling domain*
3. *Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.*

4.1.1.3 *Low-Dose Cancer Risk Estimation*

Inspection of the results for estimated collective effective dose, or size of populations receiving elevated doses, arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem) shows that (as expected) there is no difference between the results of the reference case and the results for sensitivity case HE-2. For this sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of using a dose truncation model. The ratio of the results of the reference and sensitivity case were 1.000 for all release categories and are therefore not reproduced here.

4.2 Early Health Effects

Early health effects selected for risk integration in the project include early fatalities from all causes. Early fatalities are assumed to arise from either hematopoietic syndrome, pulmonary syndrome, or gastrointestinal syndrome. These effects require large absorbed doses (several Gray) to be delivered to target organs (red bone marrow, lung tissues, or gastrointestinal tissues) over short periods (hours to days). As documented in Table 3.6-2, hematopoietic syndrome requires a dose of greater than 2.3 Gy-equivalent to the red bone marrow within the early-phase period, and prodromal vomiting requires a dose of greater than 0.5 Gy-equivalent to the stomach over the early phase. Because early fatalities are characterized by a threshold, the results may indicate zero early fatalities if doses are high but slightly below the threshold for early fatalities. To examine the potential margin for early fatality risks, a number of intermediate outputs were examined. These included the range at which early fatalities were projected to be possible, the size of the population exposed to moderate and high early-phase acute doses to the red bone marrow, and the potential for non-fatal early health effects. Prodromal vomiting was selected as an indicator output to understand how close a given cohort might be to the potential for early fatalities, as the threshold dose for prodromal vomiting is slightly lower than the threshold doses for early fatalities. Examining early injuries can indicate whether doses are close to the early fatality threshold for selected source terms.

The early fatalities are characterized both in terms of population-weighted[43] (i.e., individual) risk of an early fatality at a given distance from the release and total early fatality cases within a defined distance of the site. These effects are examined using the MACCS Type 1 output (total health effects cases) and Type 8 output (population-weighted individual fatality risk). The early fatality safety goal is generally interpreted to be the population-weighted risk of an early fatality within 1 mile of the site boundary. With the assumption in the model that the EAB is located at 0.75 miles, the safety goal risk would be defined as the risk within 1.75 miles. An alternate approach to characterizing the individual risk, which does not credit the sparseness of the population around the site, is the average individual risk[44] (which is described later in this section).

Table 4.2-1 shows the projected mean number of early fatalities within 50 miles. These results represent a mean value over all weather trials, and a fractional apportionment of the population of each grid element to each cohort. Because of these two factors, the mean value of the total health effect cases may be less than a single person. Such results suggest that only a limited number of trials, coupled with a very small population at risk, resulted in projected early fatalities. In Table 4.2-1, the results are given by types of cohorts as well as overall, in order to evaluate which populations are at risk. EVAC refers to the sum of all 12 evacuating cohorts (4 cohorts each for 0–10, 10-15, and 15-20 miles); NON-EVAC refers to the non-evacuating cohort, which includes those who do not evacuate when ordered to do so, as well as those

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[43] This result is obtained using the MACCS Type 8 output.

[44] This result is obtained using the MACCS Type 4 output.

outside of the evacuation zone; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; and OVERALL refers to the combined set of all cohorts.

Table 4.2-1: Mean (across all weather trials) number of early fatality cases within 50 miles, by release category and cohort type*

Release Category	EVAC	NON-EVAC	SCH	SHADOW	IND	OVERALL
V-F	7.1E-06	4.7E-05	-	-	-	5.4E-05
V-F-SC	-	1.0E-05	-	-	-	1.0E-05
V	-	-	-	-	-	-
SGTR-O	-	6.2E-06	-	-	-	6.2E-06
SGTR-O-SC	-	-	-	-	-	-
SGTR-C	-	-	-	-	-	-
ISGTR	-	1.4E-06	-	-	-	1.4E-06
CIF	-	-	-	-	-	-
CIF-SC	-	-	-	-	-	-
ECF	-	-	-	-	-	-
LCF	-	-	-	-	-	-
LCF-SC	-	-	-	-	-	-
ICF-BURN	-	-	-	-	-	-
ICF-BURN-SC	-	-	-	-	-	-
BMT	-	-	-	-	-	-
NOCF	-	-	-	-	-	-

Note: EVAC refers to the sum of all 12 evacuating cohort; NON-EVAC refers to the non-evacuating cohort; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; and OVERALL refers to the combined set of all cohorts.

**Mean values for health effects cases of less than one arise from fractional populations coupled with infrequent occurrence of adverse weather.*

Because early fatalities are threshold phenomena requiring individual doses greater than 2.32 Gy-equivalent to the red bone marrow, the potential for a cliff-edge effect can be examined by examining the size of the population subject to high, but non-fatal, doses. To explore the margin to a potential cliff-edge effect, the total number of projected prodromal vomiting cases, a non-fatal early health effect that occurs at a slightly lower dose, was examined in Table 4.2-2. Table 4.2-2 shows a similar pattern to Table 4.2-1, although with higher numbers (albeit still very low, with less than a single case on average). This suggests that only a very small population would be expected to receive the high acute doses needed to yield early fatalities.

Table 4.2-2: Mean (across all weather trials) number of early injury (prodromal vomiting) cases within 50 miles*

Release Category	EVAC	NON-EVAC	SCH	SHADOW	IND	OVERALL
V-F	6.9E-03	2.2E-03	-	-	-	9.1E-03
V-F-SC	6.0E-03	1.7E-03	-	-	-	7.7E-03
V	-	-	-	-	-	-
SGTR-O	-	1.2E-03	-	-	-	1.2E-03
SGTR-O-SC	-	-	-	-	-	-
SGTR-C	-	-	-	-	-	-
ISGTR	-	9.2E-04	-	-	-	9.2E-04
CIF	-	2.2E-08	-	-	-	2.2E-08
CIF-SC	-	-	-	-	-	-
ECF	-	1.2E-05	-	-	-	1.2E-05
LCF	-	-	-	-	-	-
LCF-SC	-	-	-	-	-	-
ICF-BURN	-	-	-	-	-	-
ICF-BURN-SC	-	-	-	-	-	-
BMT	-	-	-	-	-	-
NOCF	-	-	-	-	-	-

Note: EVAC refers to the sum of all 12 evacuating cohort; NON-EVAC refers to the non-evacuating cohort; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; and OVERALL refers to the combined set of all cohorts.

**Mean values for health effects cases of less than one arise from fractional populations coupled with infrequent occurrence of adverse weather.*

As seen in Table 4.2-1, early fatality cases were generally observed (if at all) only in the non-evacuating cohort. It was observed by staff inspection of intermediate results that the only evacuating cohort with the potential for early fatalities was the evacuation tail within 10 miles. These two cohorts were therefore selected for detailed examination.

The risk to an individual may be represented either by estimating the population-weighted risk (the total number of fatalities normalized by the total population within a region, which in this analysis is estimated as 1 mile from the site boundary) or an average individual risk assuming that there is an individual at a specified distance (which in this analysis is estimated in the ring immediately outside the 0.75-mile site boundary). Comparison of these two results, one of which accounts for the distribution of population around the site (the MACCS Type 8 population-weighted risk) and one of which does not (the MACCS Type 4 average individual risk), may provide insights on how the distribution of population can affect the computed risk. As seen in Table 4.2-3, comparison of the population-weighted individual risk to the average individual risk shows that the low individual risk may be related to the sparse population within 1 mile of the site boundary. Only a few sectors have any population within this distance, such that the likelihood that the wind is blowing into a populated sector at close range is relatively low.

Table 4.2-3: Mean (across all weather trials) value of individual early fatality risk, by release category and cohort type

Release Category	Population-Weighted EF Risk, 0–1.8 miles			Average Individual EF Risk, 0.7-1 miles	
	1GPT	NON-EVAC	OVERALL	1GPT	NON-EVAC
V-F	2.9E-06	3.6E-04	2.1E-06	4.3E-05	1.6E-03
V-F-SC	-	7.9E-05	4.0E-07	4.3E-05	1.2E-03
V	-	-	-	-	-
SGTR-O	-	5.0E-05	2.5E-07	-	7.3E-04
SGTR-O-SC	-	-	-	-	-
SGTR-C	-	-	-	-	-
ISGTR	-	1.1E-05	5.6E-08	-	8.5E-04
CIF	-	-	-	-	-
CIF-SC	-	-	-	-	-
ECF	-	-	-	-	1.7E-09
LCF	-	-	-	-	-
LCF-SC	-	-	-	-	-
ICF-BURN	-	-	-	-	-
ICF-BURN-SC	-	-	-	-	-
BMT	-	-	-	-	-
NOCF	-	-	-	-	-

Note: 1 GPT refers to the evacuation tail cohort; NON-EVAC refers to the non-evacuating cohort; and OVERALL refers to the combined set of all cohorts.

The range at which early fatalities may occur can be illustrated by examining the results for the early fatality distance shown in Table 4.2-4, including both the mean and the 95th percentile. Examination of this table shows that the distances at which early fatalities are possible are either within the 0.75-mile site boundary or only slightly beyond, where there is very limited population. This is consistent with the information in Figure 4.1-2, showing the very rapid decline in the likelihood of doses exceeding 200 rad-eq to the red bone marrow for the non-evacuating cohort. For the slowest evacuating tail cohort, the ranges (shown in Table 4.2-4) at which early fatalities are possible are lower than for the non-evacuating cohort. It should be noted that the release categories giving rise to early fatalities generally were of high magnitude. As documented in Table 3.4-20, the relocation times for the non-evacuating cohort for these higher magnitude releases were assumed to be relatively large, due to the larger modeled evacuation area. If a more rapid relocation time were selectively applied to distances within a few miles of the site, these results would likely be lower.

Table 4.2-4: Range in miles at which early fatality risk >0 for non-evacuating and 10-mile tail cohorts, mean (across all weather trials) and 95th percentile

Release Category	NON-EVAC, Mean	NON-EVAC, 95th Percentile	1GPT, Mean	1GPT, 95th Percentile
V-F	1.1E+00	2.1E+00	5.6E-01	9.2E-01
V-F-SC	9.5E-01	1.9E+00	5.2E-01	7.8E-01
V	-	-	-	-
SGTR-O	8.7E-01	1.7E+00	-	-
SGTR-O-SC	-	-	-	-
SGTR-C	1.0E-01	****	-	-
ISGTR	8.7E-01	1.2E+00	1.2E-01	****
CIF	2.3E-01	5.3E-01	-	-
CIF-SC	2.3E-01	5.3E-01	-	-
ECF	2.7E-01	5.8E-01	-	-
LCF	8.6E-05	-	-	-
LCF-SC	-	-	-	-
ICF-BURN	-	-	-	-
ICF-BURN-SC	-	-	-	-
BMT	-	-	-	-
NOCF	-	-	-	-

Note: 1 GPT refers to the 10-mile evacuation tail cohort; NON-EVAC refers to the non-evacuating cohort.

***** indicates that the mean value is greater than the 95th percentile*

The weather conditions leading to early fatalities can be examined by use of the MACCS RISCAT output. This output shows the relative contribution of each weather bin to the mean value of any MACCS result of interest. A graphical representation of this output is shown in Figures 4.2-1 (for the contribution of weather bins and release categories to the total number of early fatality cases) and 4.2-2 (for the contribution of weather bins and release categories to the risk to an individual within 1 mile of the site boundary of early fatality). Examination of Figures 4.2-1 and 4.2-2 suggests that early fatalities arise primarily under low wind speed, slightly stable, or stable conditions. This is reasonable given that these conditions give rise to relatively high centerline air and ground concentrations. The relative likelihood of these conditions may have a dependence upon the time of day or the season of the year, which could also affect the evacuation behavior. They could also have a dependence upon the relative frequency with which the wind blows towards close-in populated sectors. However, these potential dependencies were not explored in this analysis. Because these early fatality results appear to arise from only a few weather bins, the effect of alternate weather years in which these bins were relatively more or less frequent than the selected year may be more pronounced for estimation of early fatality risk. Of note is that the mean results are dominated by the relatively more frequent stable, low wind speed conditions, and not by precipitation events.

The contribution of release categories to the mean value of the total number of early fatality cases and to the mean risk to an individual within 1 mile of the site boundary of early fatality is shown in Figure 4.2-3. These results are consistent with the observation from Tables 4.2-1 and

4.2-3, namely, that bypass events (ISLOCA or SGTR cases) are the dominant contributor to early fatality risk.

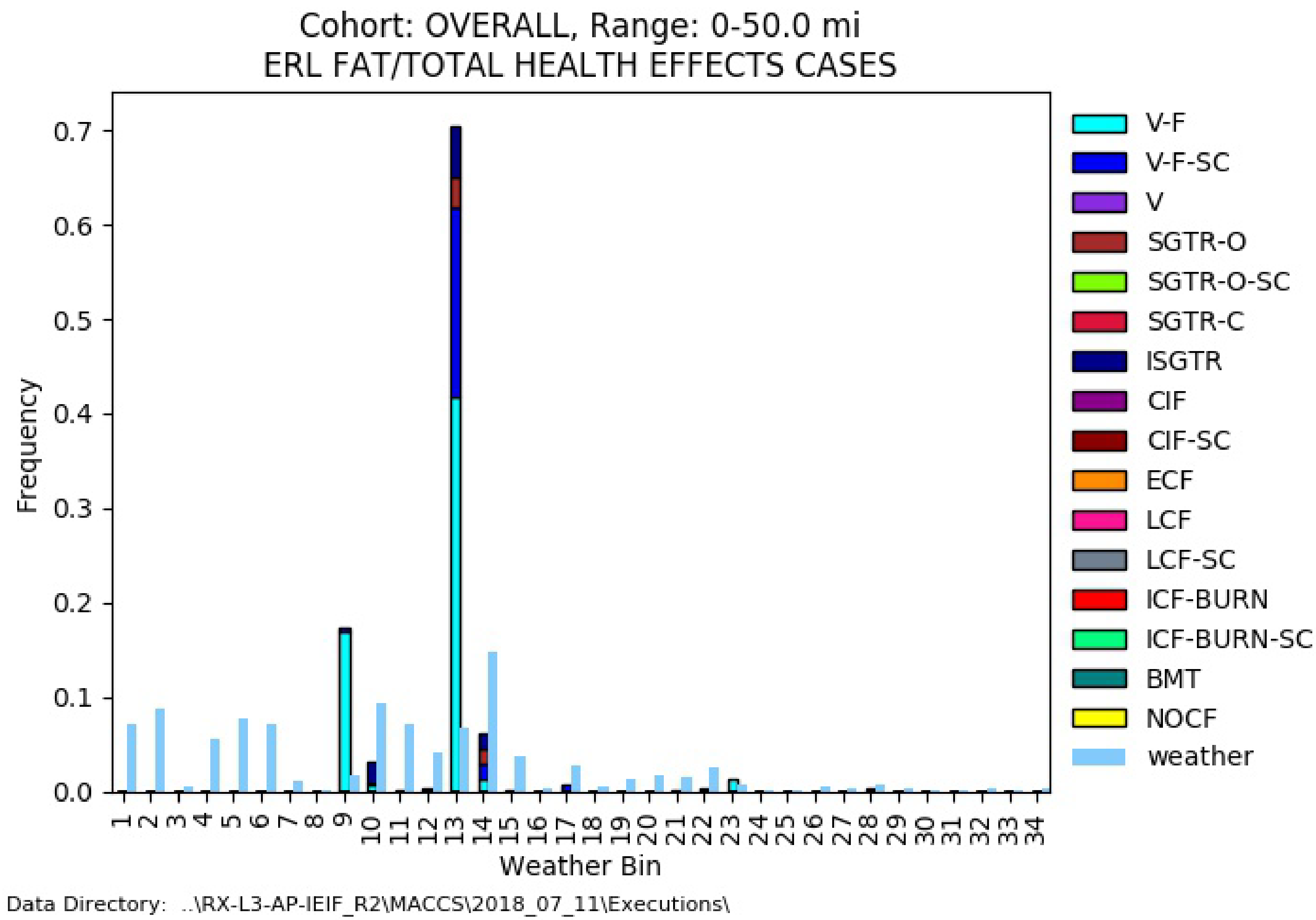


Figure 4.2-1: Relative contribution of weather bins and release categories to mean (across all weather trials) number of early fatality cases

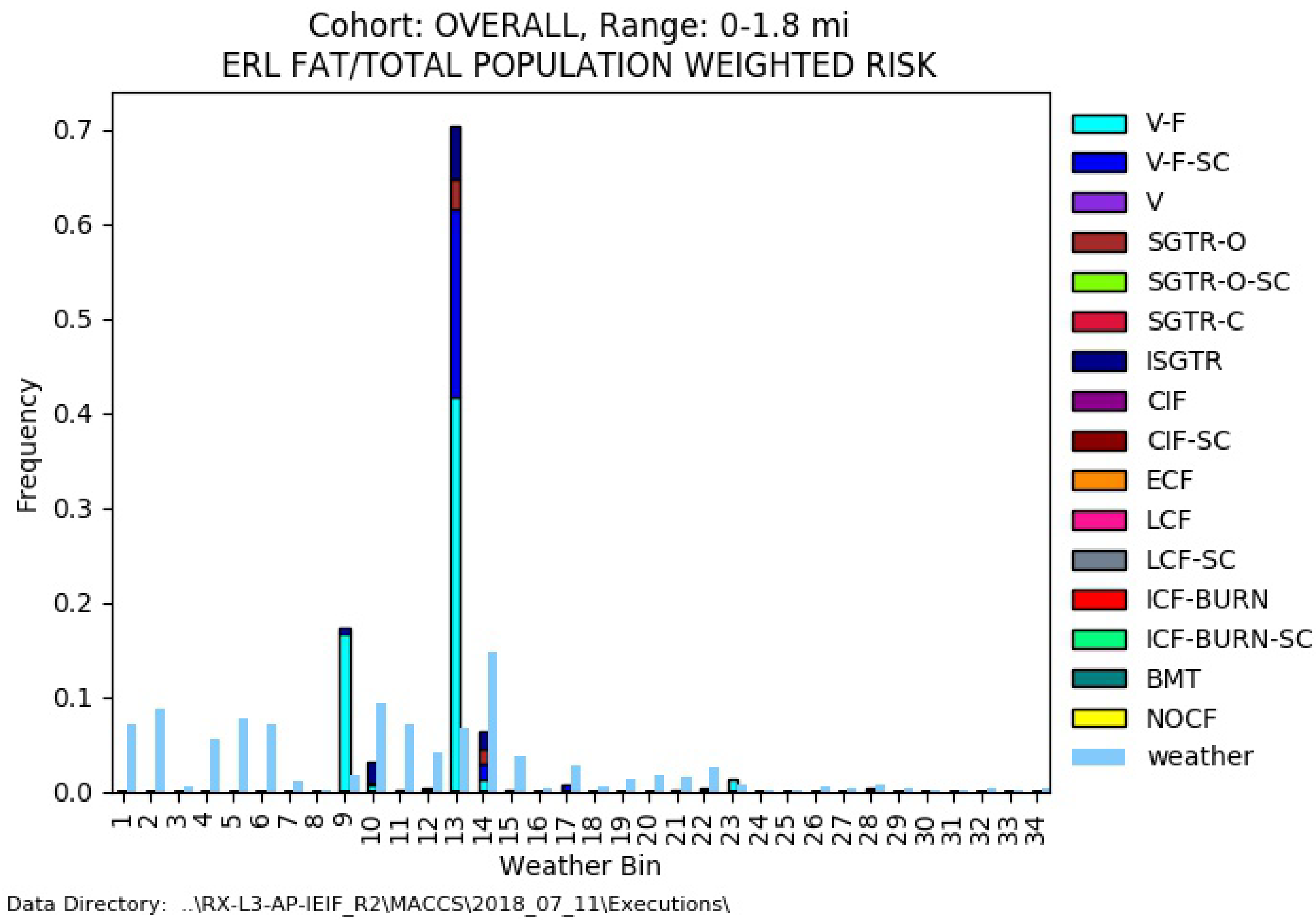
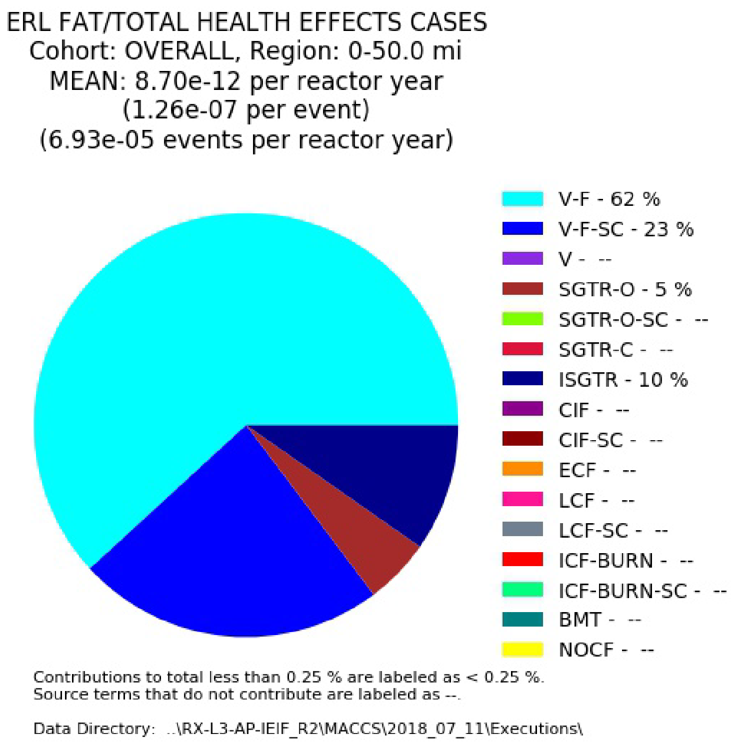
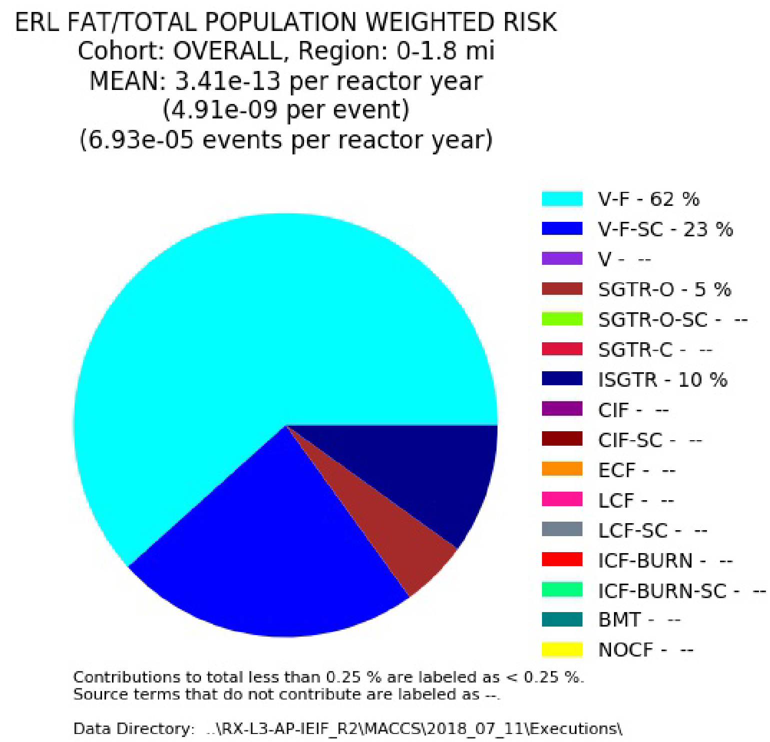


Figure 4.2-2: Relative contribution of weather bins and release categories to mean (across all weather trials) population-weighted individual early fatality risk within 1.8 miles



Early Fatalities within 50 Miles



Population-Weighted Individual Early Fatality Risk within 1 mile of Site Boundary

Figure 4.2-3: Contribution of release categories to mean early fatality risk

The complementary cumulative distribution functions of the total number of early fatality cases, and the risk to an individual within 1 mile of the site boundary of early fatality are shown in Figure 4.2-4 and 4.2-5, respectively. The results shown in those figures are consistent with the results seen in Figures 4.2-3; namely, that the risk of early fatality is largely driven by the V-F, V-F-SC, and ISGTR release categories.

In summary, the projected number of early fatalities is very low. In this analysis, it is effectively zero, as Figure 4.2-4 shows that the chance of having even a single early fatality is less than 10^{-11} per reactor-critical-year. To the extent that it is possible, it would arise within the non-evacuating population residing very close to the site under adverse (stable, low wind speed) meteorological conditions, although for the worst case (V-F) there is a very slight chance of early fatalities arising within the 10-mile evacuation tail cohort (1GPT). The risks are also low because of the sparse population within the region where early fatalities are possible, which makes the likelihood that the wind is blowing into a populated sector with meteorological conditions that could lead to early fatalities extremely low. Early fatalities in this analysis appear to arise only under the unlikely combination of all of the following conditions:

- Occurrence of a bypass event (ISLOCA or SGTR cases) with a relatively large and fast release
- Occurrence of adverse meteorological conditions (primarily, stable, low wind speed conditions)
- Wind blowing in the direction of a populated sector very close to the site
- Delayed or slow evacuation of the populations toward which the winds are blowing

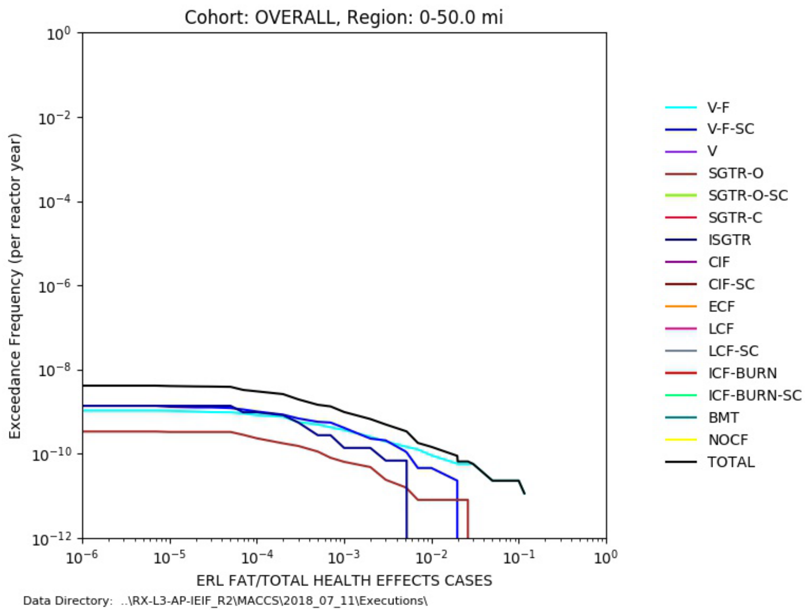


Figure 4.2-4: Complementary cumulative distribution function of total early fatality cases within 50 miles

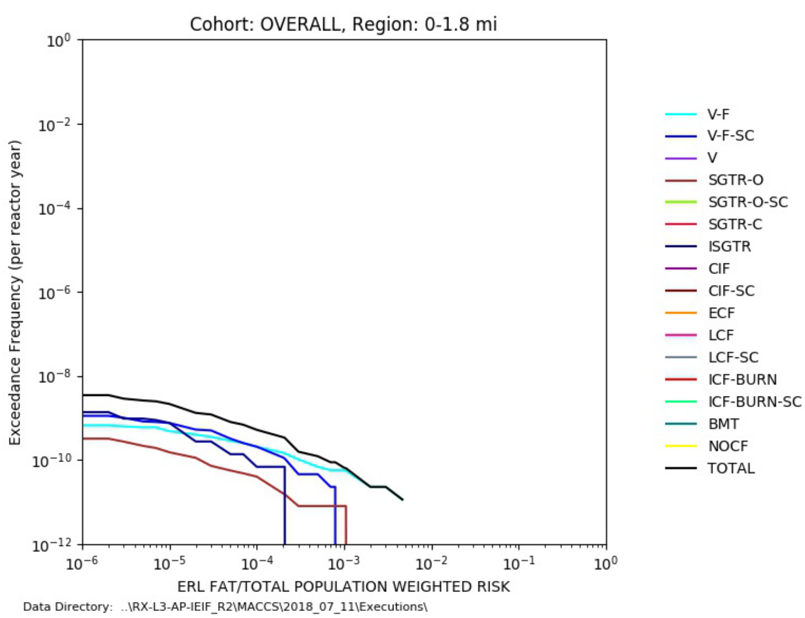


Figure 4.2-5: Complementary cumulative distribution function of population-weighted individual early fatality risk within 1 mile of site boundary

4.2.1 Sensitivity Cases

4.2.1.1 *Meteorological Sampling*

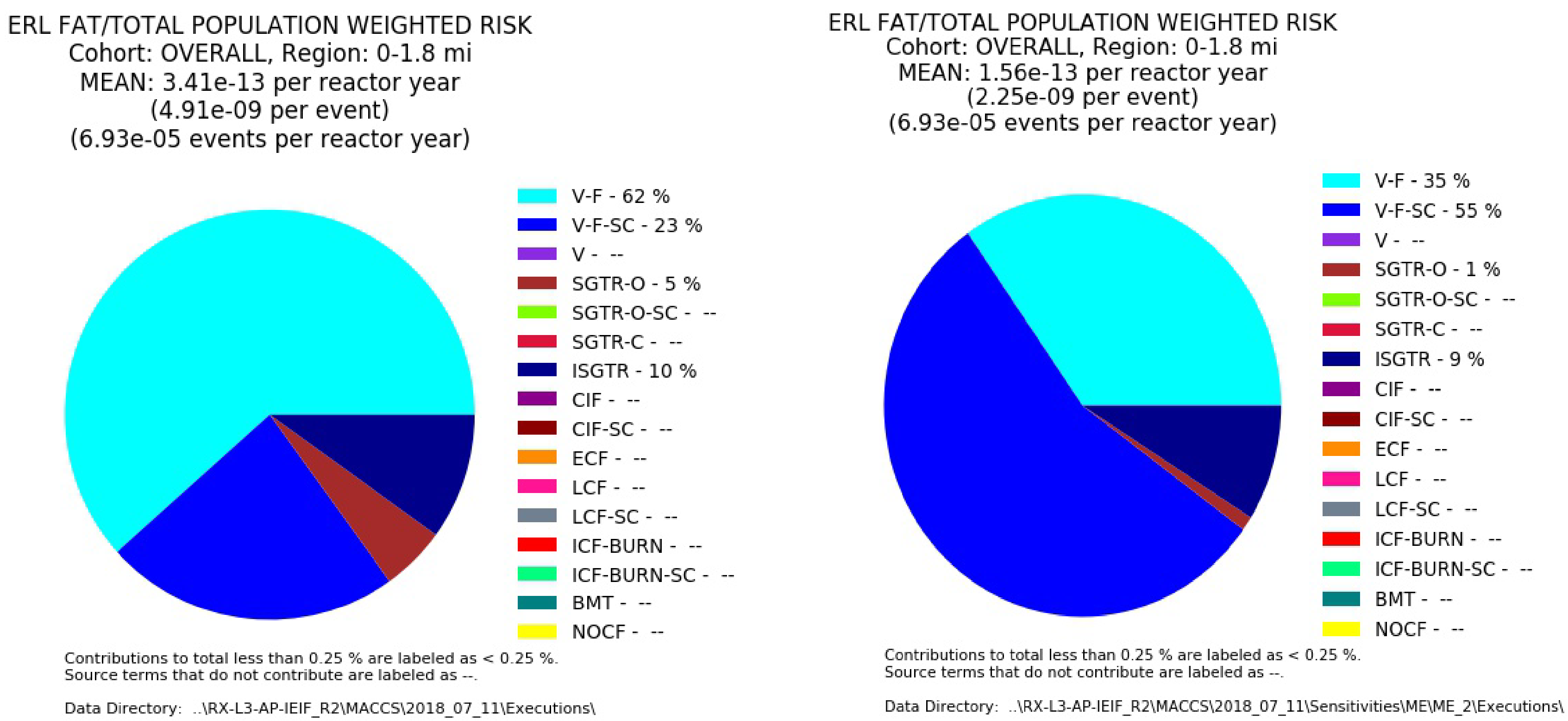
The effect of sampling only a subset of the meteorological data on the risk of early health effects is shown in Table 4.2-5 through Table 4.2-7. The sensitivity of these metrics, which represent the small subset of the population that may receive high doses, is similar to that of the population receiving elevated doses seen in Table 4.1-3 and Table 4.1-4. The overall frequency weighted results can vary by a factor of approximately two and the effect on individual release categories can vary between a factor of approximately 0.1 to 1.1 This increased sensitivity is consistent with the observation that high doses arise from adverse but infrequent weather conditions, and sampling less than the complete set of all weather trials may miss some of these adverse weather conditions. The effect of meteorological sampling on the relative contribution of release categories to early health effects is shown in Figure 4.2-6 and Figure 4.2-7. Although the same four release categories are identified as the dominant contributors to early fatality risk, the relative contributions are slightly different.

Table 4.2-5: Individual early fatality risk, 0–1.8 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**3.4E-13**	**1.6E-13**	**0.457**
V-F	1.0E-07	2.1E-06	5.4E-07	0.258
V-F-SC	2.0E-07	4.0E-07	4.3E-07	1.083
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	2.5E-07	2.4E-08	0.098
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	5.6E-08	2.3E-08	0.410
CIF	7.0E-08	-	-	-
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	-	-	-
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Base Case ME_2

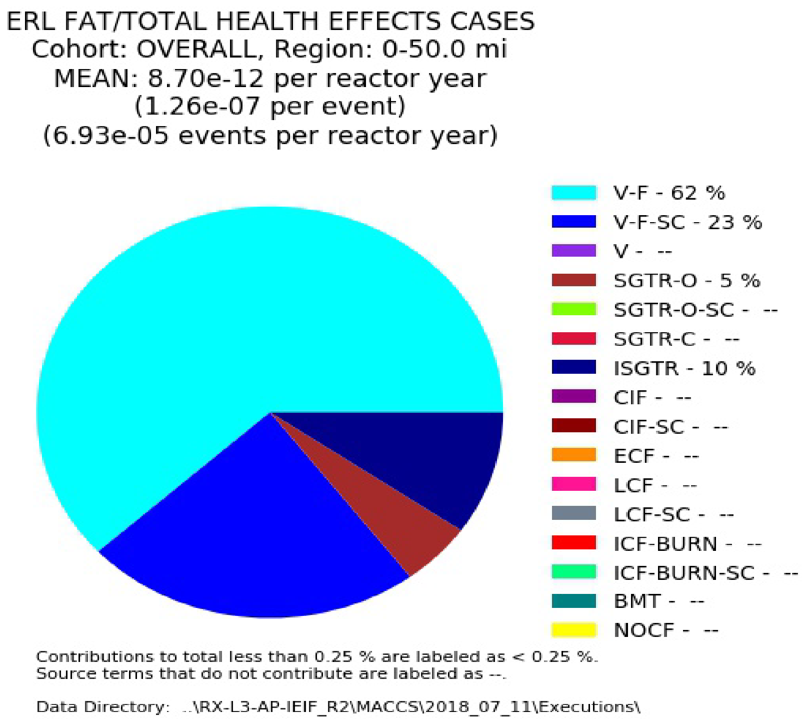
Figure 4.2-6: Contribution of release categories to mean population-weighted individual early fatality risk within 1 mile of the site boundary: ME_2

Table 4.2-6: Early fatality cases, 0–50 mi (persons) (mean value across all weather trials): ME_2

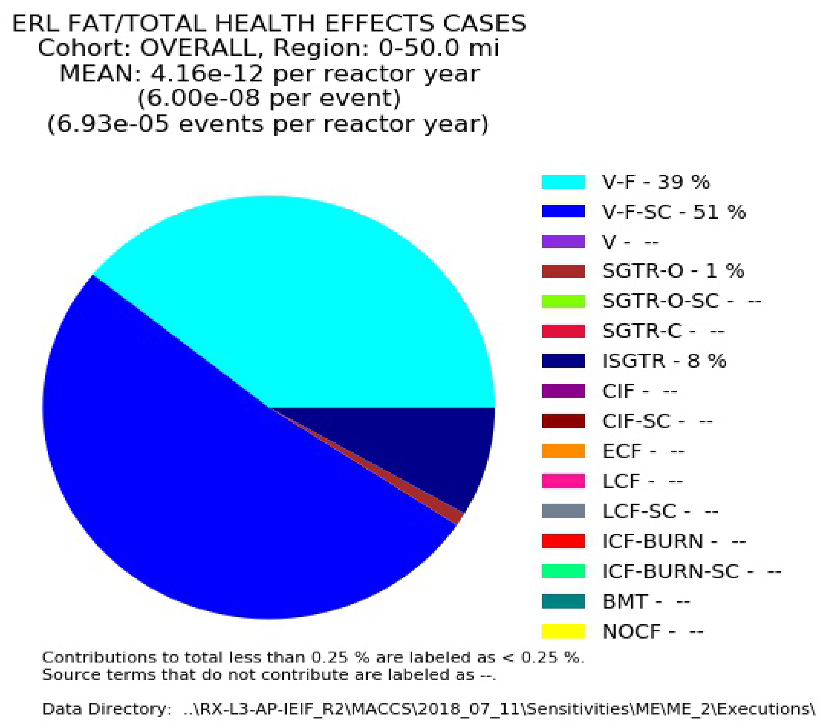
Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**8.7E-12**	**4.2E-12**	**0.478**
V-F	1.0E-07	5.4E-05	1.6E-05	0.303
V-F-SC	2.0E-07	1.0E-05	1.1E-05	1.049
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	6.2E-06	6.1E-07	0.098
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	1.4E-06	5.8E-07	0.411
CIF	7.0E-08	-	-	-
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	-	-	-
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Base Case



ME_2

Figure 4.2-7: Contribution of release categories to mean early fatality cases, 0–50 mi: ME_2

Table 4.2-7: Early injury (prodromal vomiting) cases, 0–50 mi (persons) (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**3.1E-09**	**3.0E-09**	**0.959**
V-F	1.0E-07	9.1E-03	5.7E-03	0.629
V-F-SC	2.0E-07	7.7E-03	8.5E-03	1.114
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	1.2E-03	9.9E-04	0.838
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	9.2E-04	1.0E-03	1.093
CIF	7.0E-08	2.2E-08	-	0.000
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	1.2E-05	6.6E-06	0.534
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories
2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.2.1.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on the risk of early health effects is shown in Table 4.2-8 through Table 4.2-10. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time. It can be seen that the effect of terminating the release 36 hours after SAMG entry has minimal impacts on the risk of early health effects, suggesting the potential for elevated doses is largely attributable to that portion of the release that occurs within 36 hours after SAMG entry[45]. This is similar to the effect of accident termination on the size of the population receiving elevated doses is demonstrated in Tables 4.1-7 and 4.1-8.

[45] Tables 4.2-8 to 4.2-10 show a slight (≤1 percent) increase in early health effect risks for the ISGTR release category. The reason for this very slight increase is not currently known.

Table 4.2-8: Individual early fatality risk, 0–1.8 mi (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**1.6E-13**	**1.6E-13**	**1.001**
V-F	1.0E-07	5.4E-07	5.4E-07	1.000
V-F-SC	2.0E-07	4.3E-07	4.3E-07	1.000
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	2.4E-08	2.4E-08	1.000
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	2.3E-08	2.3E-08	1.009
CIF	7.0E-08	-	-	-
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	-	-	-
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.2-9: Early fatality cases, 0–50 mi, persons (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**4.2E-12**	**4.2E-12**	**1.001**
V-F	1.0E-07	1.6E-05	1.6E-05	1.000
V-F-SC	2.0E-07	1.1E-05	1.1E-05	1.000
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	6.1E-07	6.1E-07	1.000
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	5.8E-07	5.8E-07	1.007
CIF	7.0E-08	-	-	-
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	-	-	-
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-	-	-
NOCF	2.4E-05	-	-	-

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.2-10: Early injury (prodromal vomiting) cases, 0–50 mi, persons (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**3.0E-09**	**3.0E-09**	**1.002**
V-F	1.0E-07	5.7E-03	5.7E-03	1.000
V-F-SC	2.0E-07	8.5E-03	8.5E-03	1.000
V	7.0E-08	-	-	-
SGTR-O	7.0E-08	9.9E-04	9.9E-04	1.000
SGTR-O-SC	2.0E-07	-	-	-
SGTR-C	7.0E-08	-	-	-
ISGTR	6.0E-07	1.0E-03	1.0E-03	1.010
CIF	7.0E-08	-	-	-
CIF-SC	7.0E-08	-	-	-
ECF	7.0E-08	6.6E-06	6.6E-06	1.000
LCF	2.9E-05	-	-	-
LCF-SC	3.0E-06	-	-	-
ICF-BURN	9.0E-06	-	-	-
ICF-BURN-SC	2.0E-06	-	-	-
BMT	8.0E-07	-		
NOCF	2.4E-05	-		

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.2.1.3 *Low-Dose Cancer Risk Estimation*

Inspection of the results for estimated early health effects arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem) shows that (as expected) there is no difference between the results of the reference case and the results for sensitivity case HE-2. For this sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of using a dose truncation model. The ratio of the results of the reference and sensitivity case were 1.000 for all release categories and are therefore not reproduced here.

4.3 Latent Health Effects

Latent fatalities in the L3PRA project are modeled as arising from leukemia, bone cancer, breast cancer, lung cancer, thyroid cancer, liver cancer, colon cancer, and residual cancers. The base-case dose-response model assumes a linear, no threshold dose-response function. Latent health effects are examined using the MACCS Type 1 output (total health effects cases) and Type 8 output (population-weighted individual fatality risk). The latent fatalities are characterized both in terms of total latent fatality cases within 50 and 100 miles from the point of release and the population-weighted risk of a latent fatality averaged over the region within 10 miles of the point of release. It should be noted that the population-weighted risk values (MACCS Type 8) include only the direct exposure pathways (i.e., groundshine, cloudshine, cloud inhalation, and resuspension inhalation) and exclude the ingestion (i.e., food and water consumption) pathways. The values for total latent fatality cases (MACCS Type 1) include both the late-phase indirect exposure pathways and the direct exposure pathways.

4.3.1 Total Latent Fatalities

A breakdown of the number of latent fatality cases by release category and cohort type is shown in Table 4.3-1a (within 50 miles) and Table 4.3-1b (within 100 miles). The results are given by types of cohorts as well as overall, in order to evaluate which populations are at risk. EVAC refers to the sum of all 12 evacuating cohorts (4 cohorts each for 0–10, 10-15, and 15-20 miles); NON-EVAC refers to the non-evacuating cohort, which includes those who do not evacuate when ordered to do so, as well as those outside of the evacuation zone; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; CHRONC refers to the number of cases arising after the late (recovery) phase has ended; and OVERALL refers to the combined set of all cohorts.

Table 4.3-1a: Mean (across all weather trials) number of latent fatality cases within 50 miles

Release Category	EVAC	NON-EVAC	SCH	SHADOW	IND	CHRONC	OVERALL
V-F	6	53	-	<1	1	137	197
V-F-SC	5	42	-	<1	1	108	156
V	<1	1	-	-	<1	5	6
SGTR-O	5	60	-	<1	<1	256	321
SGTR-O-SC	<1	4	-	<1	<1	31	35
SGTR-C	<1	4	-	<1	<1	53	57
ISGTR	3	52	-	<1	<1	219	275
CIF	<1	30	-	<1	-	190	220
CIF-SC	<1	27	-	<1	-	153	181
ECF	2	73	-	<1	-	300	374
LCF	<1	14	-	-	<1	84	98
LCF-SC	<1	1	-	-	-	15	15
ICF-BURN	<1	44	-	<1	-	176	219
ICF-BURN-SC	<1	<1	-	-	-	1	1
BMT	<1	<1	-	-	<1	1	1
NOCF	<1	<1	-	-	-	1	1

Note: EVAC refers to the sum of all 12 evacuating cohort; NON-EVAC refers to the non-evacuating cohort; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; and OVERALL refers to the combined set of all cohorts.

Table 4.3-1b: Mean (across all weather trials) number of latent fatality cases within 100 miles

Release Category	EVAC	NON-EVAC	SCH	SHADOW	IND	CHRONC	OVERALL
V-F	6	115	-	<1	1	394	516
V-F-SC	5	91	-	<1	1	294	391
V	<1	2	-	-	<1	10	12
SGTR-O	5	149	-	<1	<1	869	1020
SGTR-O-SC	<1	8	-	<1	<1	62	70
SGTR-C	<1	8	-	<1	<1	98	105
ISGTR	3	121	-	<1	<1	533	657
CIF	<1	57	-	<1	-	361	418
CIF-SC	<1	51	-	<1	-	293	345
ECF	2	161	-	<1	-	863	1030
LCF	<1	25	-	-	<1	161	186
LCF-SC	<1	1	-	-	-	27	28
ICF-BURN	<1	88	-	<1	-	382	470
ICF-BURN-SC	<1	<1	-	-	-	1	1
BMT	<1	<1	-	-	<1	2	2
NOCF	<1	<1	-	-	-	2	2

Note: EVAC refers to the sum of all 12 evacuating cohort; NON-EVAC refers to the non-evacuating cohort; SCH refers to the schools cohort, if modeled; SHADOW refers to the 20 percent of the population immediately outside of the evacuation zone that voluntarily evacuates; IND refers to the industrial facility employees; and OVERALL refers to the combined set of all cohorts.

Examination of the mean number of latent fatalities within 50 and 100 miles by release category and accident phase (including inspection of the MACCS intermediate results), suggests the following:

- Most cases (80-90 percent) arise in the late phase and therefore result from exposures to populations that are either never subject to long-term protective actions, or who reoccupy properties after decontamination and/or natural weathering have reduced doses to below the habitability criteria. As seen earlier in Figures 4.1-1b and 4.1-2b, this is associated with mean chronic lifetime doses on the order of 1-10 rem or lower.
- The majority of the early-phase contributions to the total are associated with the populations beyond the 20-mile evacuation zone. Outside the evacuation zone, the population is assigned to the non-evacuating cohort. As seen earlier in Figures 4.1-1a and 4.1-2a, this cohort is characterized by mean lifetime doses on the order of 1-10 rem or lower.
- The relative increase in projected total latent fatality cases arising from exposures beyond 50 miles is, on average, about a factor of 2. However, the magnitude of the relative increase is dependent upon the magnitude of the release.

The increase in projected total latent fatality cases arising from exposures beyond 50 miles is dependent upon the magnitude of the release. As seen in Figure 4.1-1b, showing the peak total effective dose (rem) from late-phase exposure, the lower magnitude releases (such as the NOCF, BMT, and ICF-BURN-SC) result in exposures being concentrated closer to the site, whereas larger magnitude releases may give rise to elevated exposures at longer distances, suggesting that the collective effects will converge more slowly for those cases.

The relative contribution of different weather bins and release categories to the mean number of latent fatality cases within 50 and 100 miles is shown in Figures 4.3-1a and 4.3-1b, respectively. The stacked bar on the left shows the relative contribution to the mean for a particular weather bin from each release category. The solid blue bar to the right shows the relative frequency of the weather bin. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. These figures suggest that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value. This suggests that this result may not be particularly sensitive to the selection of alternate weather years, because there do not appear to be weather conditions that contribute disproportionately to the mean value.

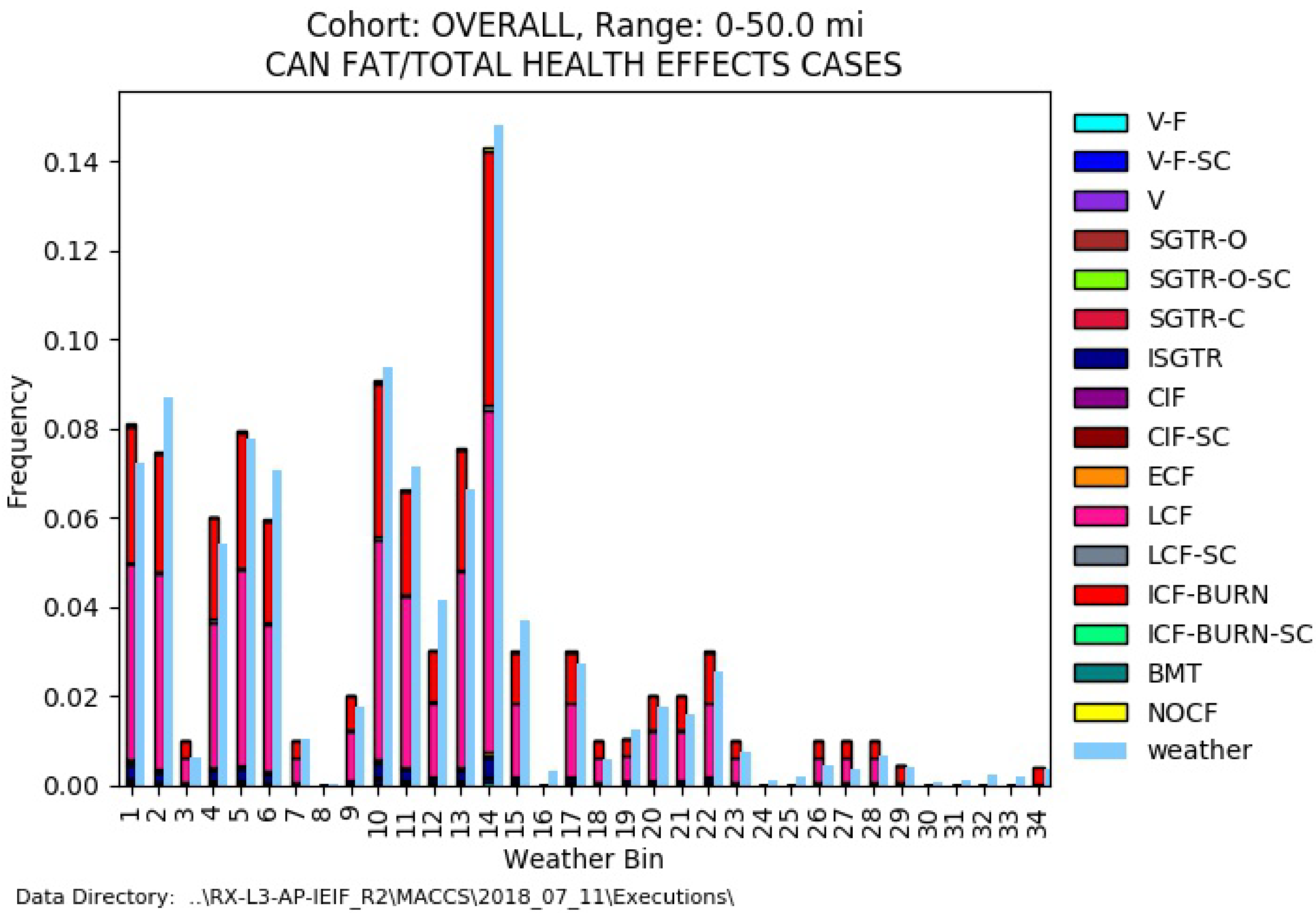


Figure 4.3-1a: Relative contribution of weather bins and release categories to mean (across all weather trials) number of latent fatality cases within 50 miles

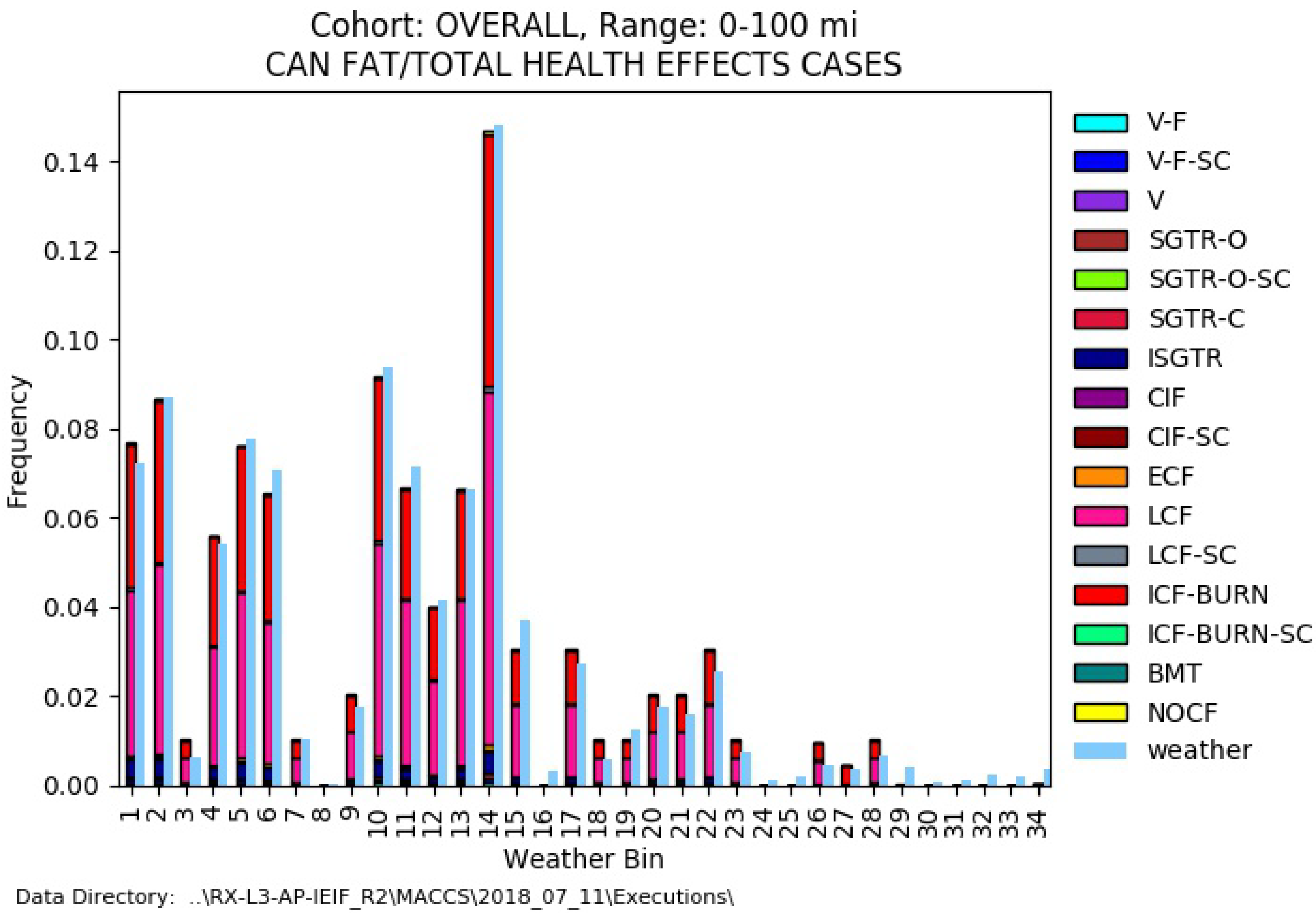


Figure 4.3-1b: Relative contribution of weather bins and release categories to mean (across all weather trials) number of latent fatality cases within 100 miles

The discussion above has focused on the mean values across all weather trials. The complementary cumulative distribution function provides information on the variability of the results as a result of weather conditions and different release categories. The CCDF curves for total latent fatality cases, for 0–50 miles and 0–100 miles, are shown in Figures 4.3-2a and 4.3-2b, respectively. As was the case for collective effective dose, release categories LCF and ICF-BURN appear to be the main contributors to the total number of latent fatalities, particularly at the higher frequencies.

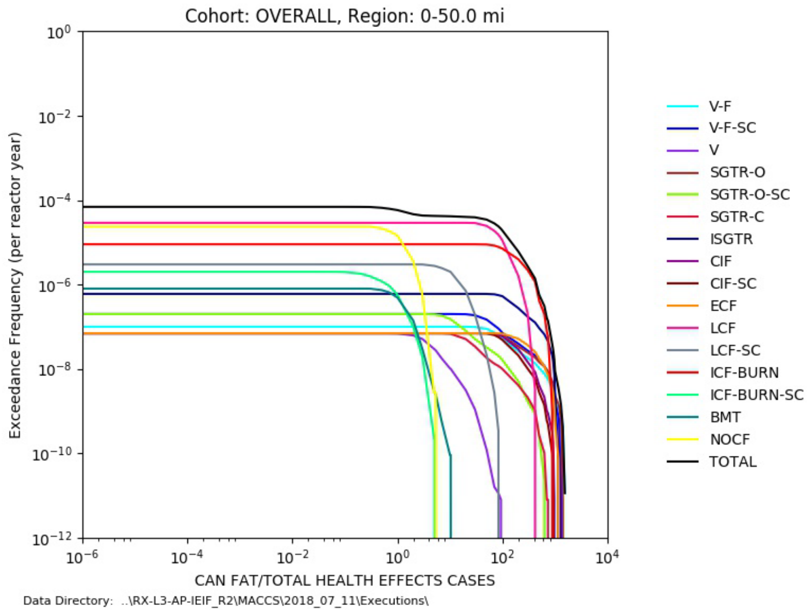


Figure 4.3-2a: Complementary cumulative distribution function, latent fatality cases, 0–50 miles

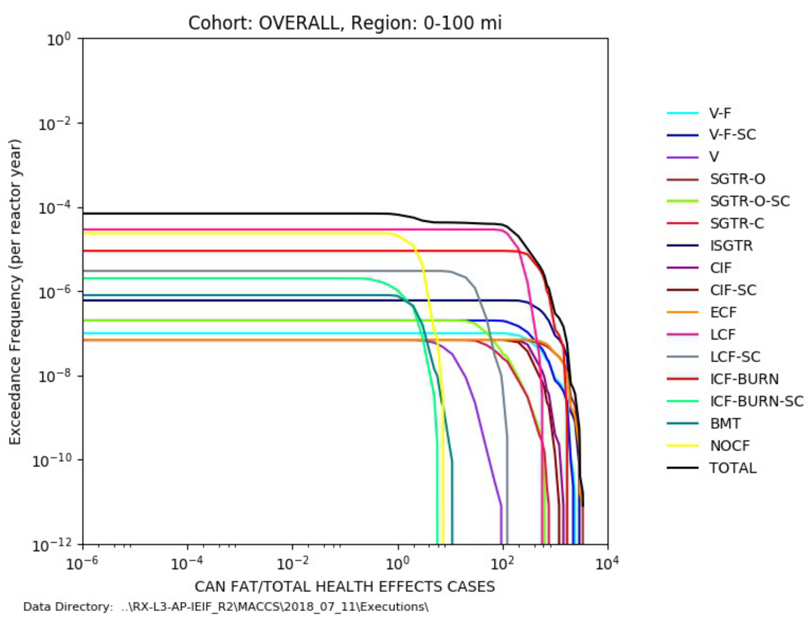


Figure 4.3-2b: Complementary cumulative distribution function, latent fatality cases, 0–100 miles

4.3.2 Population-Weighted Individual Latent Fatality Risk

The mean value of the Type 8 population-weighted individual latent cancer fatality risk within 10 miles is shown below by release category and cohort in Figure 4.3-3 and Table 4.3-2. Figure 4.3-3 shows the mean results by release category and accident phase. Table 4.3-2 shows a more detailed breakdown by release category and cohort. Since, by definition, only those cohorts within 10 miles will contribute to the risk within 10 miles, only those cohorts are shown in Table 4.3-2. The fraction of population within 10 miles for each early-phase cohort and the release category frequency are also given in Table 4.3-2.

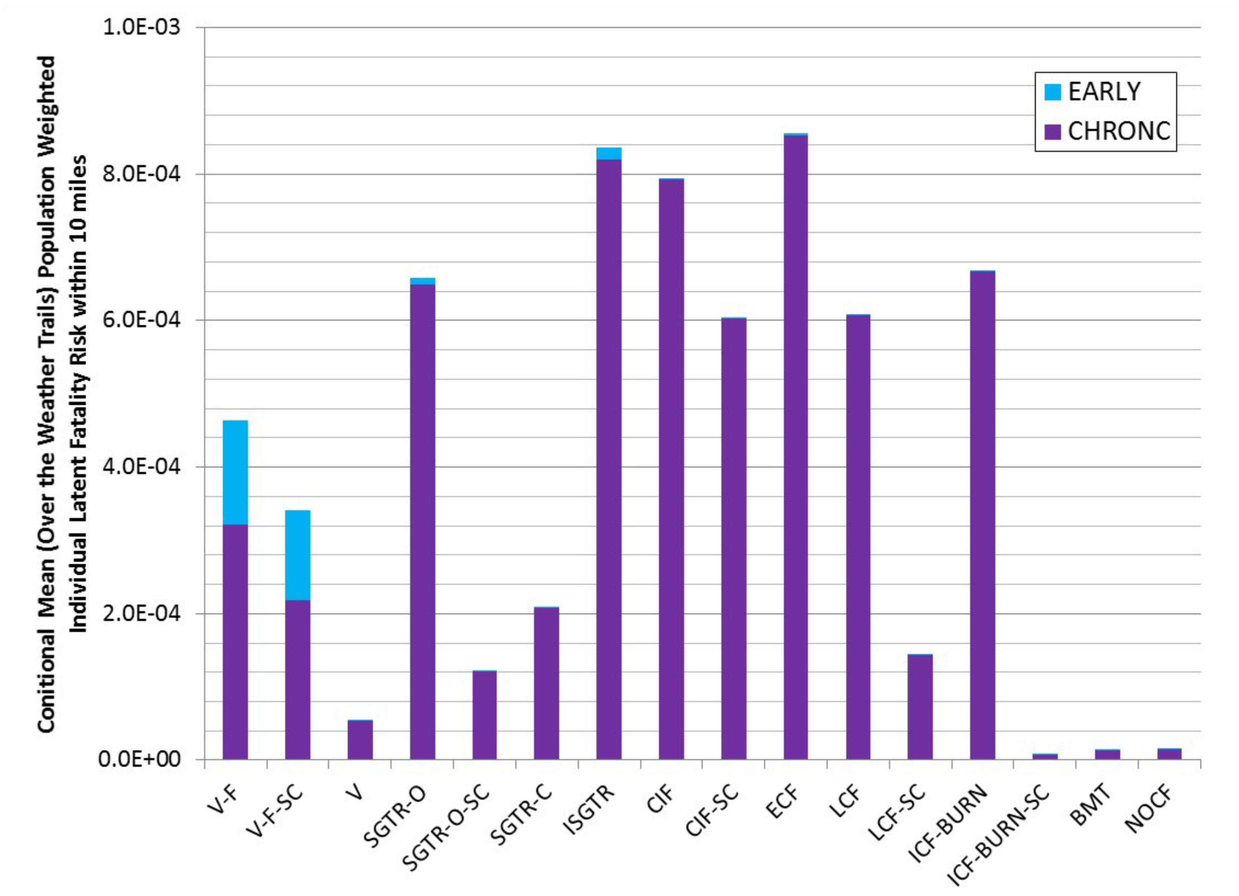


Figure 4.3-3: Conditional population-weighted individual latent fatality risk within 10 miles by release category and accident phase

Table 4.3-2: Mean (across all weather trials) value of the population-weighted individual latent cancer fatality risk within 10 miles, by release category and cohort (fraction of population within 10 miles for each early-phase cohort given in parentheses)

Release Category	FREQ (/rcy)	1GP1 (18%)	1GP2 (18%)	1GP3 (18%)	1GPT (6.1%)	IND (38%)	NON EVAC (0.3%)	EARLY (100%)	CHRONC (100%)	OVER ALL
ALL[1] (per rcy)	**6.9E-05**	**1.5E-12**	**1.6E-12**	**2.0E-11**	**2.5E-10**	**6.6E-11**	**6.9E-09**	**6.6E-11**	**2.5E-08**	**2.5E-08**
V-F	1.0E-07	1.3E-06	1.5E-06	6.7E-05	7.3E-04	2.0E-04	2.2E-03	1.4E-04	3.2E-04	4.6E-04
V-F-SC	2.0E-07	1.1E-06	1.2E-06	6.1E-05	6.3E-04	1.7E-04	1.8E-03	1.2E-04	2.2E-04	3.4E-04
V	7.0E-08	1.9E-08	1.9E-08	5.0E-08	2.6E-06	6.3E-07	2.1E-05	4.8E-07	5.3E-05	5.4E-05
SGTR-O	7.0E-08	1.2E-06	1.2E-06	1.2E-06	1.8E-05	1.2E-06	2.4E-03	9.7E-06	6.5E-04	6.6E-04
SGTR-O-SC	2.0E-07	2.3E-08	2.3E-08	2.4E-08	1.0E-06	1.3E-07	7.0E-05	3.4E-07	1.2E-04	1.2E-04
SGTR-C	7.0E-08	4.4E-08	4.4E-08	4.6E-08	1.6E-06	2.1E-07	7.1E-05	4.2E-07	2.1E-04	2.1E-04
ISGTR	6.0E-07	1.0E-06	1.0E-06	1.0E-06	7.6E-05	1.6E-05	1.7E-03	1.7E-05	8.2E-04	8.4E-04
CIF	7.0E-08	1.6E-07	1.6E-07	1.6E-07	1.6E-07	0.0E+00	3.7E-04	1.2E-06	7.9E-04	7.9E-04
CIF-SC	7.0E-08	1.4E-07	1.4E-07	1.4E-07	1.4E-07	0.0E+00	3.2E-04	1.1E-06	6.0E-04	6.0E-04
ECF	7.0E-08	2.0E-07	2.0E-07	2.0E-07	2.0E-07	0.0E+00	7.7E-04	2.5E-06	8.5E-04	8.6E-04
LCF	2.9E-05	5.2E-09	7.7E-09	2.1E-08	7.5E-08	2.5E-08	1.3E-04	4.3E-07	6.1E-04	6.1E-04
LCF-SC	3.0E-06	1.1E-10	1.1E-10	1.1E-10	1.1E-10	0.0E+00	1.7E-05	5.2E-08	1.4E-04	1.4E-04
ICF-BURN	9.0E-06	2.4E-08	2.4E-08	2.4E-08	2.4E-08	0.0E+00	1.1E-04	3.6E-07	6.7E-04	6.7E-04
ICF-BURN-SC	2.0E-06	2.8E-11	2.8E-11	2.8E-11	2.8E-11	0.0E+00	1.3E-06	4.0E-09	7.8E-06	7.8E-06
BMT	8.0E-07	2.3E-10	2.3E-10	5.1E-10	1.3E-08	3.8E-09	5.8E-06	2.0E-08	1.3E-05	1.3E-05
NOCF	2.4E-05	5.8E-11	5.8E-11	5.8E-11	5.8E-11	0.0E+00	2.7E-06	8.3E-09	1.4E-05	1.4E-05

Note: FREQ: Frequency; 1GP1, 1GP2, and 1GP3 refer to the first, second, and third 30% of the evacuating public; 1 GPT refers to the 10-mile evacuation tail; NON-EVAC refers to the non-evacuating cohort; IND refers to the industrial facility employees; EARLY refers to the population-weighted sum of all early phase cohorts; CHRON refers to the combined late-phase cohort; and OVERALL refers to the combined set of all cohorts.

1. Results are a frequency-weighted sum of all release categories

Inspection of the results in Table 4.3-2 shows that the vast majority of the relative contribution to the mean arises from late-phase exposures to the CHRONC cohort. Figures 4.3-3 through 4.3-5 shows the relationship between the early- and late-phase contributions to the population-weighted individual latent fatality risk within 10 miles. It can be seen in Figure 4.3-4 that only those releases having warning times on the order of 2 hours yield early-phase risks comparable to the late-phase risks. As expected, the late-phase risk is less dependent on the warning time. The apparent dropoff with very long warning times (over 100 hours) is likely due to the much lower releases from these release categories (i.e., the LCF-SC, BMT, and NOCF release categories). These results highlight the significance of bypass scenarios for having the potential for yielding elevated doses.

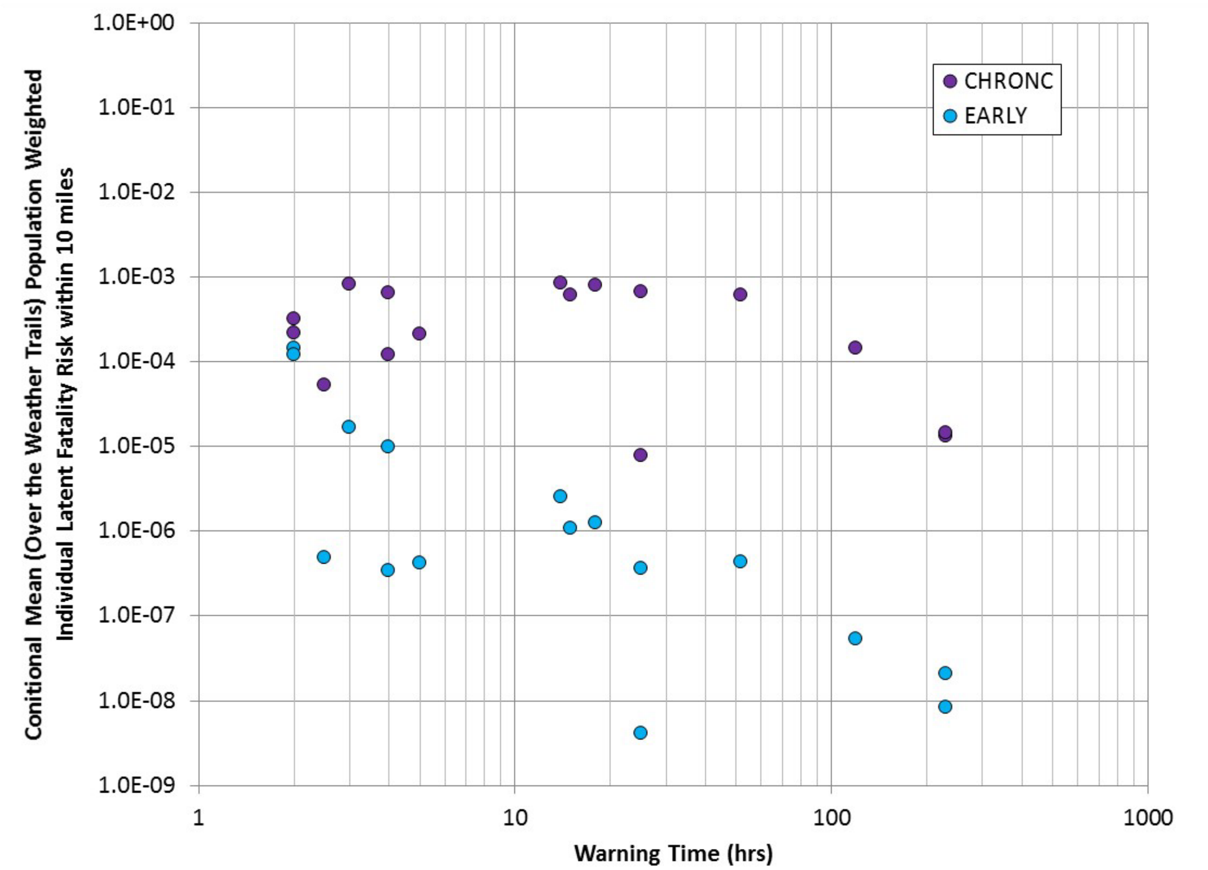


Figure 4.3-4: Mean (across all weather trials) early- and late-phase population-weighted individual latent fatality risk within 10 miles, relative to warning time

As seen in Figure 4.3-5, the late-phase component appears to become sublinear at high cesium release fractions, most likely because the potential exposures in the recovery phase are effectively constrained by effective protective actions.

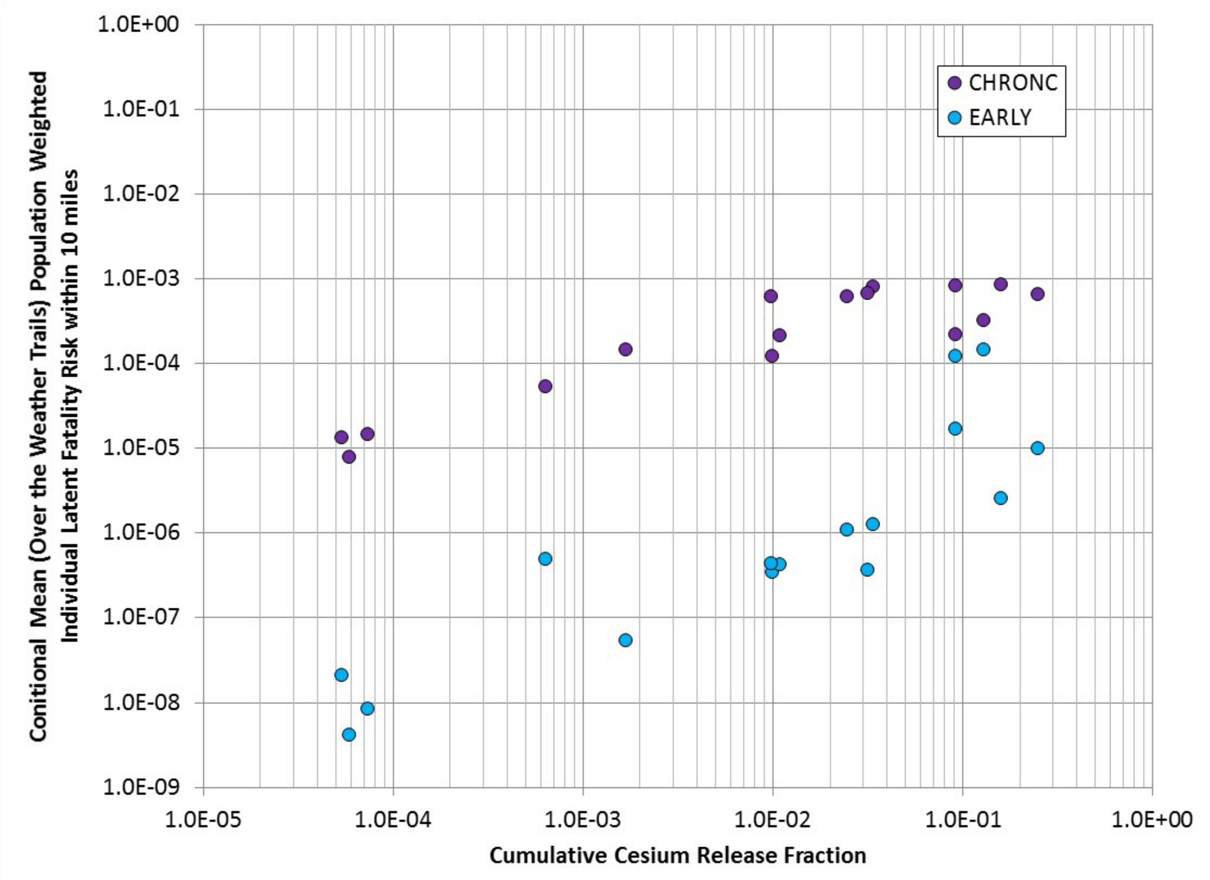


Figure 4.3-5: Mean (across all weather trials) early- and late-phase population-weighted individual fatality risk within 10 miles as a function of cesium release fraction

The relative contribution of the individual release categories to the overall mean value is shown in Figure 4.3-6. The relatively more frequent LCF and ICF-BURN release categories, which have a conditional CHRONC phase risk that is above the average CHRONC phase risk of the release catetories, account for most of the mean value.

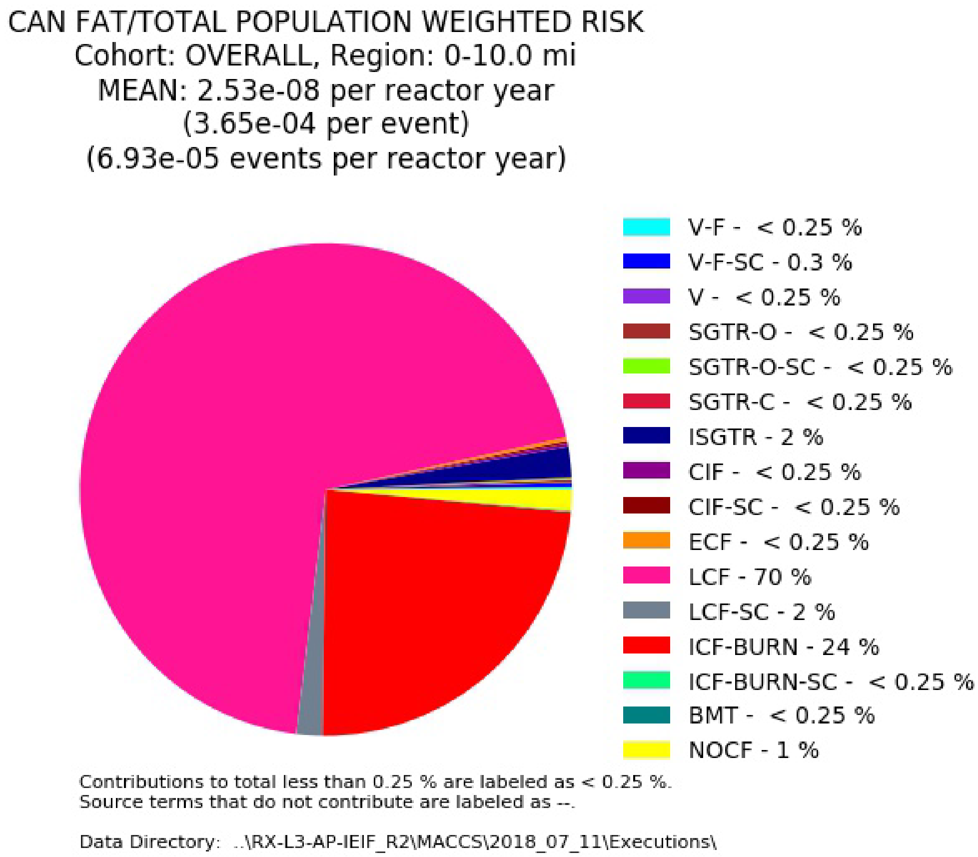


Figure 4.3-6: Relative contribution of release categories to population-weighted individual latent fatality risk within 10 miles

The relative contribution of different weather conditions to the mean population-weighted individual latent fatality risk within 10 miles is shown in Figure 4.3-7. In contrast to the analagous results for early fatality risks, the contribution from different weather bins is more evenly distributed. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. Figure 4.3-7 suggests that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value.

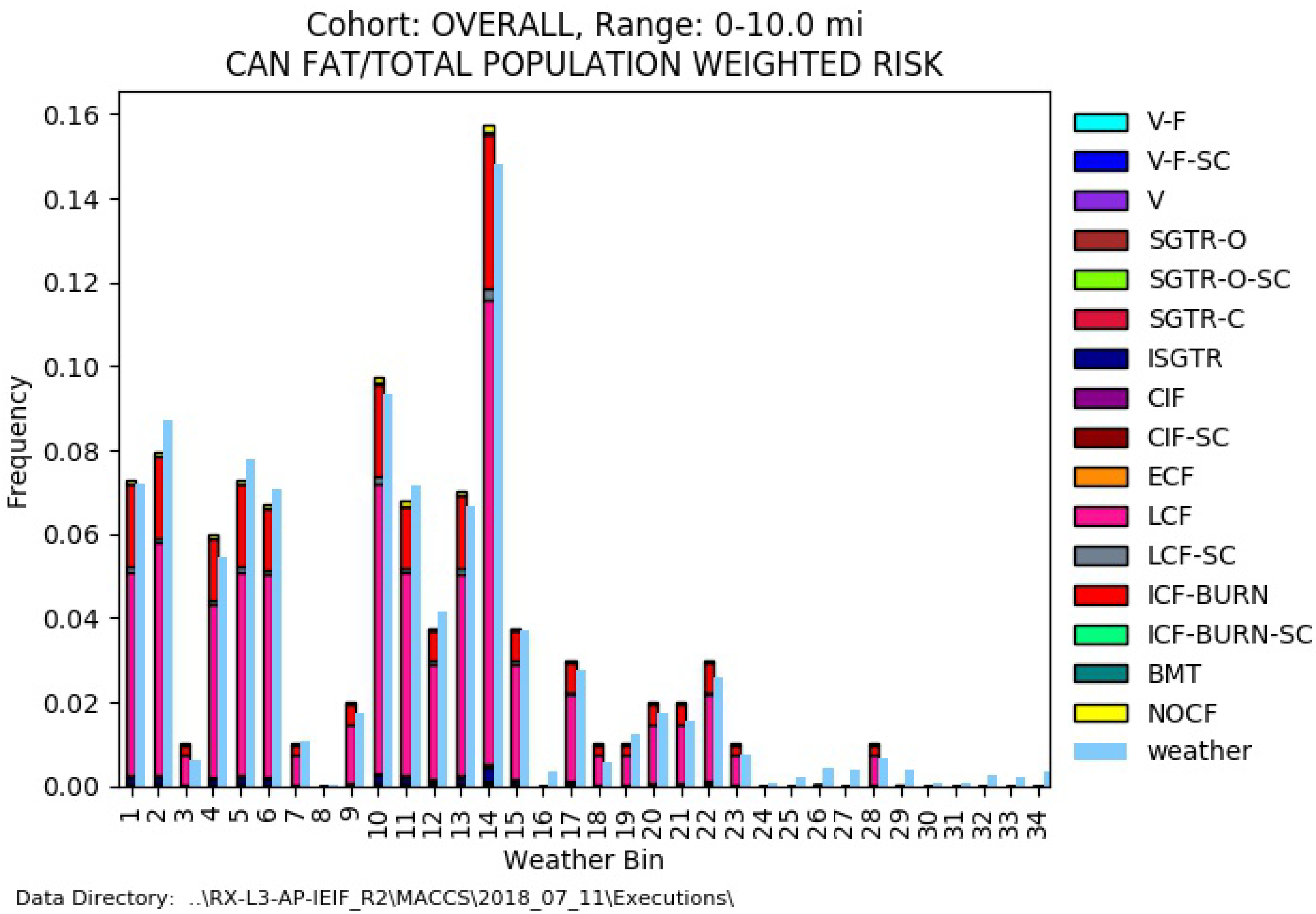


Figure 4.3-7: Relative contribution of weather bins and release categories to mean (across all weather trials) population-weighted individual latent fatality risk within 10 miles

The discussion above has focused on the mean values. The complementary cumulative distribution function provides information on the variability of the results as a result of weather conditions and different release categories. The CCDF curves for the population-weighted individual latent fatality risk are shown in Figure 4.3-8. A sharp drop in the likelihood of exceeding an individual latent fatality risk of approximately 10^{-3} per event can be seen in the graph. Inspection of intermediate results shows that this is driven by the CCDF for the late phase, which drops abruptly at this level, demonstrating that weather conditions do not drive individual risk levels higher than this for the late phase. At lower individual risk levels, the curve is dominated by the relatively more frequent LCF release category. However, at individual risk levels above 10^{-3}, the curve is driven by the lower frequency, higher consequence bypass scenarios. The effect of the relatively large, early releases from the bypass events (V-F, V-F-SC, ISGTR, and to a much lesser extent SGTR-O and ECF) are clearly visible and are consistent with the observation that while relatively infrequent, such events appear to be the only types of events capable of generating the elevated exposures capable of causing the lifetime latent fatality risks substantially greater than 10^{-3} (0.1 percent) per event. Because such exposures are also associated with an increased risk of early health effects, these are also the release categories driving the early fatality risks shown in Figures 4.2-1 and 4.2-2. The same factors that give rise to risk of early health effects (large and fast release, wind blowing in the direction of nearby populated sectors, etc.) are likely to be important factors in the potential for large individual latent fatality risks within 10 miles.

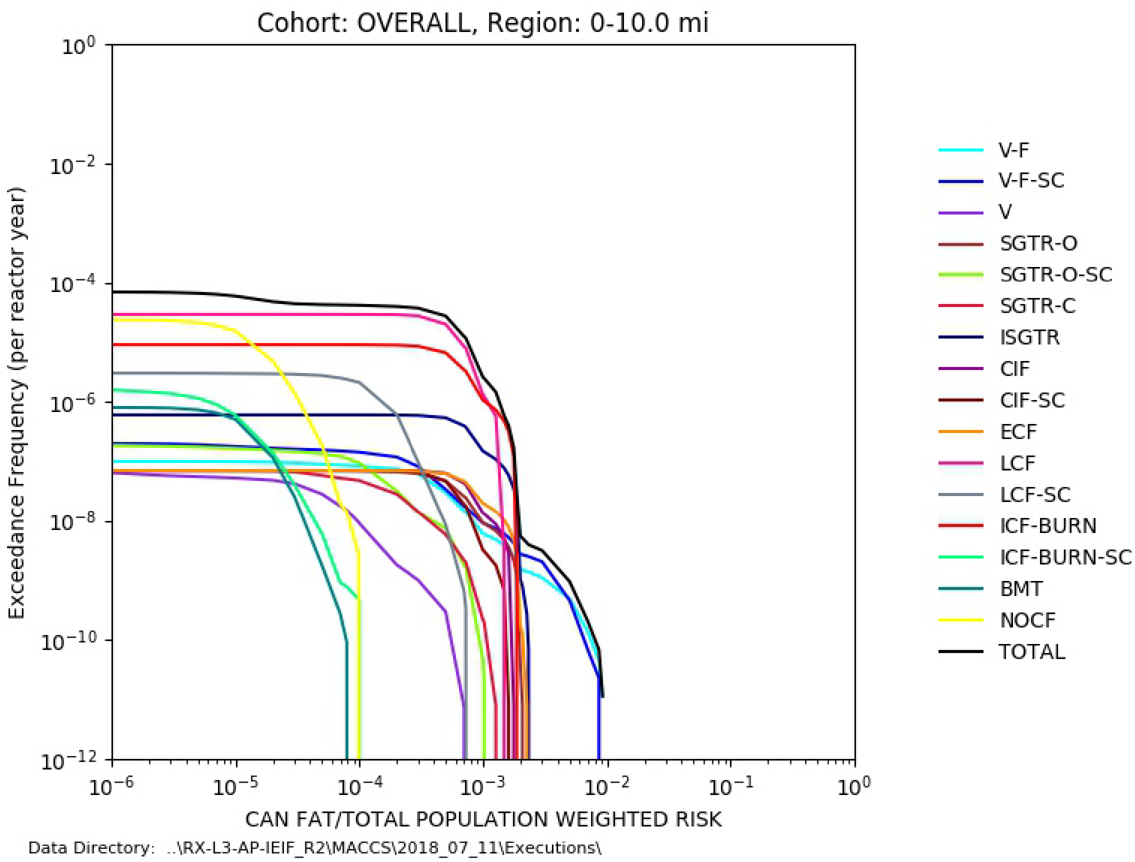


Figure 4.3-8: Complementary cumulative distribution function, population-weighted individual latent fatality risk within 10 miles

The contribution of individual cohorts to the total 0–10 mile individual (population-weighted) latent cancer fatality risk may also be examined to identify which cohorts may be most at risk, and which cohorts contribute the most to the overall CCDF when accounting for their relative size. Identification of the cohorts most at risk can be seen in Figure 4.3-9, which presents CCDF curves for the frequency-weighted total cancer fatality population-weighted risk for cohorts located within the 0–10 mile EPZ, including the overall and late-phase population-weighted total cancer fatality risk. Each curve represents the risk to a cohort weighted against the population of that cohort within the 0–10 mile interval, considering all release categories. The black curve represents the overall population-weighted risk, which reflects the total population and release category frequency.

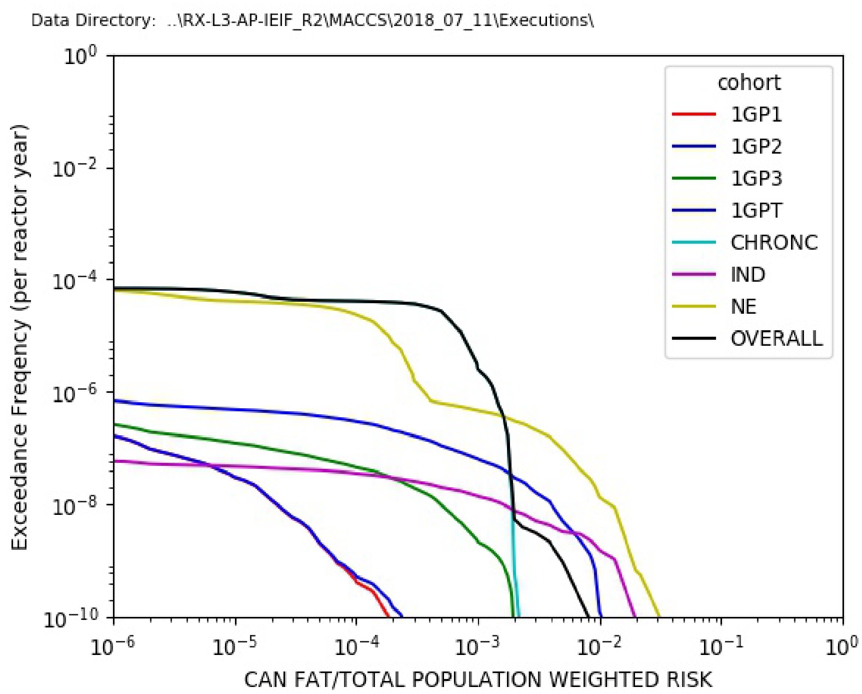


Figure 4.3-9: Complementary cumulative distribution function, population-weighted individual latent fatality risk within 10 miles: frequency-weighted for each source term and population-weighted by individual cohort population only

Figure 4.3-10 presents CCDF curves for the frequency-weighted total cancer fatality population-weighted risk for cohorts located within the 0–10 mile EPZ, but in this case the individual curves are weighted by the cohort's fraction of the 0–10 mile EPZ population. The sum of these curves (1GP1, 1GP2, 1GP3, 1GPT, IND, and CHRONC) should reflect the overall population-weighted total cancer fatality risk within the 0–10 mile region.

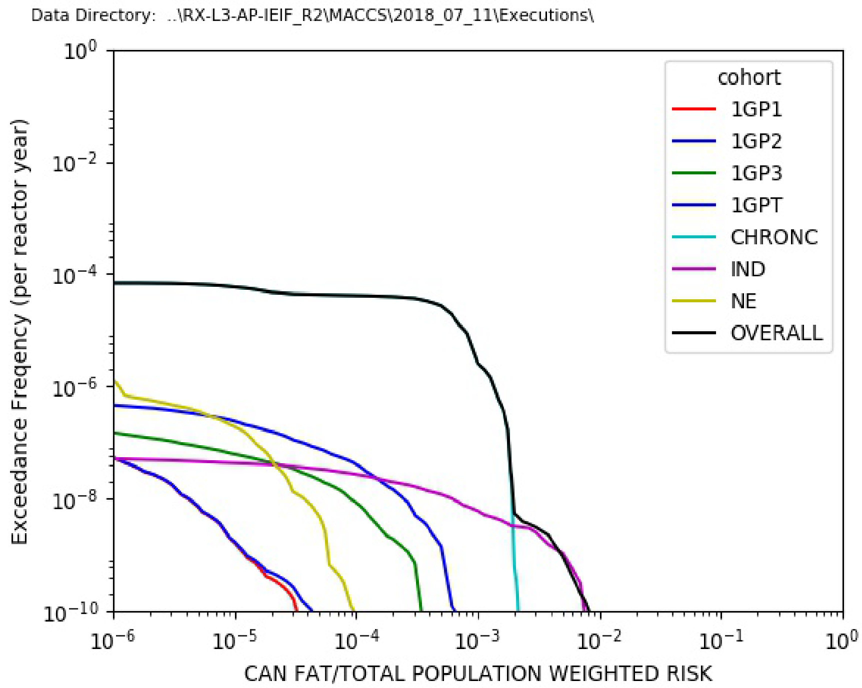


Figure 4.3-10: Complementary cumulative distribution function, population-weighted individual latent fatality risk within 10 miles: frequency-weighted for each source term and population-weighted by the entire 0–10 mile population

Several insights may be drawn from these figures:

- The risk is primarily associated with the long-term (CHRONC) exposures, not the early-phase exposures. The CHRONC cohort bounds all early-phase cohorts at an exceedance frequency of 10^{-6} per reactor-critical-year or greater, and all but the non-evacuating cohort at an exceedance frequency of 10^{-7} per reactor-critical-year or greater. At lower exceedance frequency levels, the CHRONC cohort bounds all but the non-evacuating (NE), 0–10 mile general public tail (1GPT), and the industrial facility employee (IND) cohorts.
- Figure 4.3-10 demonstrates that the highest risk, but lowest frequency, events are dominated by the IND cohort, not the non-evacuating or evacuation tail cohorts. Despite the fact that this cohort is located almost 10 miles away from the point of release, it still comprises 38 percent of the total 0–10 mile population. In contrast, the general public evacuation tail comprises only 6.1 percent of the total 0–10 mile population, and the non-evacuating cohort comprises only 0.3 percent of the total 0–10 mile population. These low relative populations result in a small contribution to the overall risk, despite the relatively higher conditional risks.

4.3.3 Sensitivity Cases

4.3.3.1 *Meteorological Sampling*

The effect of sampling only a subset of the meteorological data on the individual latent fatality risk within 10 miles, as well as on the projected total number of latent fatality cases within 50 and 100 miles is demonstrated in Table 4.3-3, Table 4.3-4, and Table 4.3-5. It is evident from inspection of these results that differences resulting from sampling a representative subset of weather trials as opposed to sampling all 8760 hourly observations are generally less than a few percent.

Table 4.3-3: Population-weighted individual latent fatality risk, 0–10 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**2.5E-08**	**2.5E-08**	**1.005**
V-F	1.0E-07	4.6E-04	4.7E-04	1.009
V-F-SC	2.0E-07	3.4E-04	3.6E-04	1.041
V	7.0E-08	5.4E-05	5.5E-05	1.032
SGTR-O	7.0E-08	6.6E-04	6.5E-04	0.983
SGTR-O-SC	2.0E-07	1.2E-04	1.3E-04	1.025
SGTR-C	7.0E-08	2.1E-04	2.1E-04	0.995
ISGTR	6.0E-07	8.4E-04	8.4E-04	1.004
CIF	7.0E-08	7.9E-04	8.0E-04	1.001
CIF-SC	7.0E-08	6.0E-04	6.0E-04	0.992
ECF	7.0E-08	8.6E-04	8.6E-04	1.007
LCF	2.9E-05	6.1E-04	6.1E-04	1.003
LCF-SC	3.0E-06	1.4E-04	1.5E-04	1.014
ICF-BURN	9.0E-06	6.7E-04	6.8E-04	1.012
ICF-BURN-SC	2.0E-06	7.8E-06	7.8E-06	0.999
BMT	8.0E-07	1.3E-05	1.3E-05	0.992
NOCF	2.4E-05	1.4E-05	1.4E-05	0.993

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.3-4: Total latent fatality cases, 0–50 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.2E-03**	**5.1E-03**	**0.985**
V-F	1.0E-07	2.0E+02	2.0E+02	1.005
V-F-SC	2.0E-07	1.6E+02	1.5E+02	0.987
V	7.0E-08	6.4E+00	6.4E+00	1.009
SGTR-O	7.0E-08	3.2E+02	3.2E+02	0.988
SGTR-O-SC	2.0E-07	3.5E+01	3.5E+01	1.014
SGTR-C	7.0E-08	5.7E+01	5.8E+01	1.009
ISGTR	6.0E-07	2.8E+02	2.7E+02	0.993
CIF	7.0E-08	2.2E+02	2.2E+02	0.986
CIF-SC	7.0E-08	1.8E+02	1.8E+02	0.989
ECF	7.0E-08	3.7E+02	3.8E+02	1.008
LCF	2.9E-05	9.8E+01	9.6E+01	0.980
LCF-SC	3.0E-06	1.5E+01	1.5E+01	1.007
ICF-BURN	9.0E-06	2.2E+02	2.2E+02	0.991
ICF-BURN-SC	2.0E-06	7.9E-01	7.9E-01	1.000
BMT	8.0E-07	1.4E+00	1.4E+00	1.015
NOCF	2.4E-05	1.3E+00	1.3E+00	0.992

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.3-5: Total latent fatality cases, 0–100 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**1.1E-02**	**1.0E-02**	**0.988**
V-F	1.0E-07	5.2E+02	5.1E+02	0.994
V-F-SC	2.0E-07	3.9E+02	4.0E+02	1.013
V	7.0E-08	1.2E+01	1.2E+01	1.000
SGTR-O	7.0E-08	1.0E+03	1.0E+03	1.000
SGTR-O-SC	2.0E-07	7.0E+01	7.1E+01	1.014
SGTR-C	7.0E-08	1.1E+02	1.1E+02	1.019
ISGTR	6.0E-07	6.6E+02	6.6E+02	1.005
CIF	7.0E-08	4.2E+02	4.1E+02	0.990
CIF-SC	7.0E-08	3.5E+02	3.4E+02	0.991
ECF	7.0E-08	1.0E+03	1.0E+03	1.000
LCF	2.9E-05	1.9E+02	1.8E+02	0.989
LCF-SC	3.0E-06	2.8E+01	2.8E+01	1.000
ICF-BURN	9.0E-06	4.7E+02	4.6E+02	0.983
ICF-BURN-SC	2.0E-06	1.3E+00	1.3E+00	1.008
BMT	8.0E-07	2.3E+00	2.3E+00	1.000
NOCF	2.4E-05	2.1E+00	2.1E+00	0.995

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.3.3.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on the individual latent fatality risk, as well as on the total latent fatality cases within 50 and 100 miles, is demonstrated in Table 4.3-6, Table 4.3-7, and Table 4.3-8. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

The effect of terminating the release is a reduction on the latent fatality risk. On a frequency-weighted basis, the reduction is approximately a factor of four. It can be seen that some release categories (such as ISLOCA or SGTR release categories) are relatively unaffected with a reduction on the order of a few percent, whereas other release categories (such as the late containment failure (LCF) release category) are reduced by almost 99%.

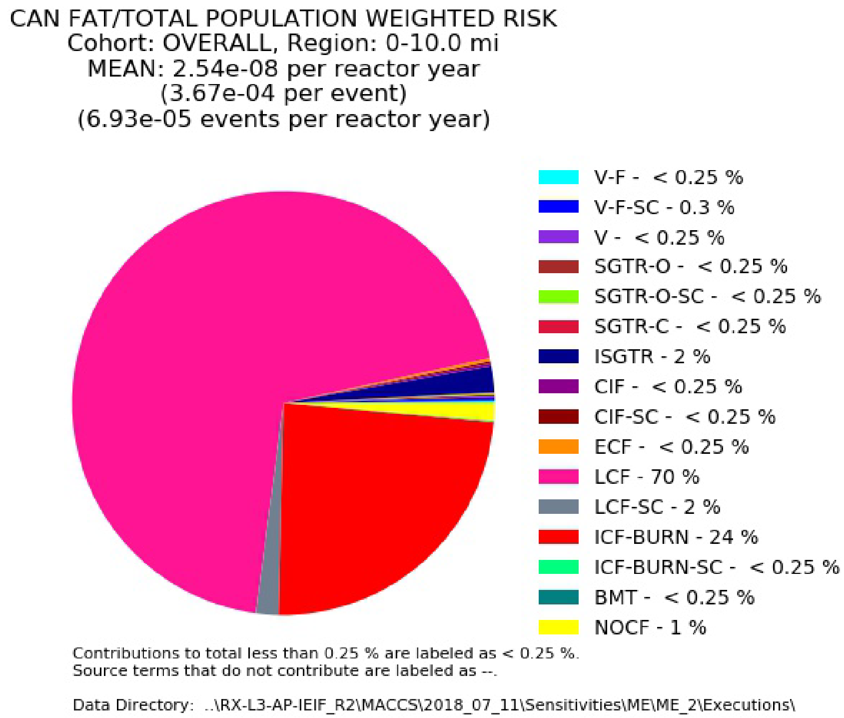
The differential impact of the accident termination time on the relative contribution of release categories to the individual latent fatality risk is illustrated in Figure 4.3-11. The frequency weighted reduction in the individual latent cancer fatality risk is a combination of the much lower conditional consequences for the LCF release category with a reduction in the conditional consequences for the ICF-BURN release category. The relative contribution of release categories to the mean individual latent fatality risk is similar to the relative contribution of release categories to the cumulative cesium release shown in Figure 4-1, with the ICF-BURN and ISGTR release categories increasing in relative importance and the LCF release category comprising a much smaller contributor.

Table 4.3-6: Population-weighted individual latent fatality risk, 0–10 mi (mean value across all weather trials): RE_4

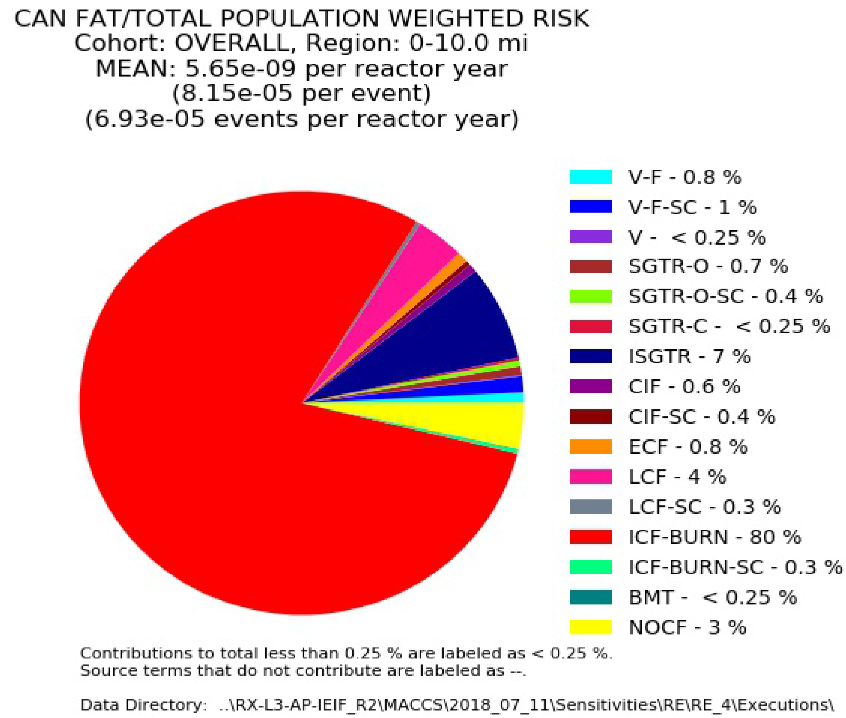
Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**2.5E-08**	**5.7E-09**	**0.222**
V-F	1.0E-07	4.7E-04	4.5E-04	0.959
V-F-SC	2.0E-07	3.6E-04	3.5E-04	0.986
V	7.0E-08	5.5E-05	5.5E-05	0.986
SGTR-O	7.0E-08	6.5E-04	5.5E-04	0.855
SGTR-O-SC	2.0E-07	1.3E-04	1.3E-04	1.000
SGTR-C	7.0E-08	2.1E-04	1.8E-04	0.879
ISGTR	6.0E-07	8.4E-04	6.8E-04	0.812
CIF	7.0E-08	8.0E-04	5.0E-04	0.634
CIF-SC	7.0E-08	6.0E-04	3.1E-04	0.519
ECF	7.0E-08	8.6E-04	6.4E-04	0.748
LCF	2.9E-05	6.1E-04	6.9E-06	0.011
LCF-SC	3.0E-06	1.5E-04	5.7E-06	0.039
ICF-BURN	9.0E-06	6.8E-04	5.0E-04	0.741
ICF-BURN-SC	2.0E-06	7.8E-06	7.8E-06	1.000
BMT	8.0E-07	1.3E-05	4.8E-06	0.368
NOCF	2.4E-05	1.4E-05	8.2E-06	0.580

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



RE_4

Figure 4.3-11: Relative contribution of release categories to population-weighted individual latent fatality risk within 10 miles: RE_4

Table 4.3-7: Total latent fatality cases, 0–50 mi (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.1E-03**	**1.3E-03**	**0.255**
V-F	1.0E-07	2.0E+02	2.0E+02	0.985
V-F-SC	2.0E-07	1.5E+02	1.5E+02	0.994
V	7.0E-08	6.4E+00	6.4E+00	0.991
SGTR-O	7.0E-08	3.2E+02	3.1E+02	0.968
SGTR-O-SC	2.0E-07	3.5E+01	3.5E+01	1.000
SGTR-C	7.0E-08	5.8E+01	5.6E+01	0.964
ISGTR	6.0E-07	2.7E+02	2.5E+02	0.930
CIF	7.0E-08	2.2E+02	1.3E+02	0.590
CIF-SC	7.0E-08	1.8E+02	9.4E+01	0.524
ECF	7.0E-08	3.8E+02	2.6E+02	0.676
LCF	2.9E-05	9.6E+01	7.6E-01	0.008
LCF-SC	3.0E-06	1.5E+01	5.8E-01	0.038
ICF-BURN	9.0E-06	2.2E+02	1.1E+02	0.507
ICF-BURN-SC	2.0E-06	7.9E-01	7.9E-01	1.000
BMT	8.0E-07	1.4E+00	5.5E-01	0.395
NOCF	2.4E-05	1.3E+00	8.4E-01	0.663

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.3-8: Total latent fatality cases, 0–100 mi (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**1.0E-02**	**2.7E-03**	**0.259**
V-F	1.0E-07	5.1E+02	5.1E+02	0.992
V-F-SC	2.0E-07	4.0E+02	4.0E+02	0.997
V	7.0E-08	1.2E+01	1.2E+01	0.992
SGTR-O	7.0E-08	1.0E+03	1.0E+03	0.980
SGTR-O-SC	2.0E-07	7.1E+01	7.1E+01	1.000
SGTR-C	7.0E-08	1.1E+02	1.0E+02	0.963
ISGTR	6.0E-07	6.6E+02	6.3E+02	0.950
CIF	7.0E-08	4.1E+02	2.4E+02	0.585
CIF-SC	7.0E-08	3.4E+02	1.8E+02	0.515
ECF	7.0E-08	1.0E+03	7.2E+02	0.700
LCF	2.9E-05	1.8E+02	1.3E+00	0.007
LCF-SC	3.0E-06	2.8E+01	1.0E+00	0.036
ICF-BURN	9.0E-06	4.6E+02	2.2E+02	0.465
ICF-BURN-SC	2.0E-06	1.3E+00	1.3E+00	1.000
BMT	8.0E-07	2.3E+00	9.0E-01	0.393
NOCF	2.4E-05	2.1E+00	1.4E+00	0.668

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.3.3.3 *Low-Dose Cancer Risk Estimation*

The effect of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem) or lifetime individual doses greater than 0.1 Sv (10 rem) on the individual latent fatality risk, as well as on the total latent fatality cases within 50 and 100 miles, is demonstrated in Table 4.3-9, Table 4.3-10, and Table 4.3-11. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

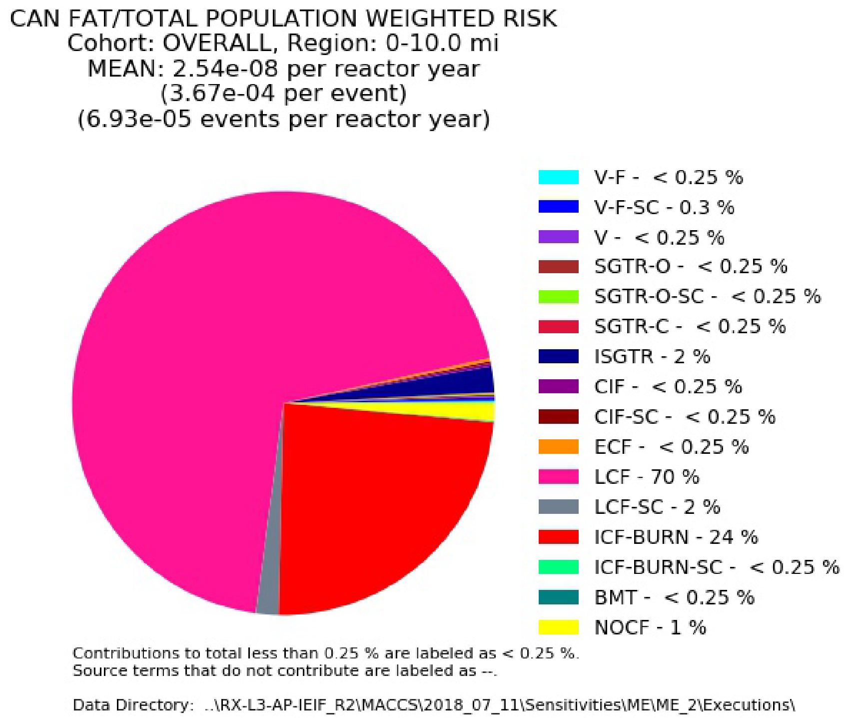
As expected, there is a significant difference in estimated latent health effect risks arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem). The overall frequency-weighted risk drops by over two orders of magnitude, and the calculated risk from many release categories is reduced by three orders of magnitude or more. However, the ISLOCA release categories that had exhibited a significant early phase contribution (as illustrated in Figure 4.3-3) exhibit a much lower reduction, albeit still significant (a factor of 3-4). The differential impact of the alternate cancer risk model on the relative contribution of release categories to the individual latent fatality risk is illustrated in Figure 4.3-12. It can be seen that bypass events (V-F, V-F-SC, and ISGTR) dominate the reduced estimated risk. The relative contribution of release categories to latent fatality risk in this sensitivity analysis is very similar to the relative contribution of release categories to early fatality risk, as seen by comparison of Figure 4.3-12 to Figure 4.2-3. This lends further support to the observation that most accidents resulting in core damage (i.e., no or late containment failure, intermediate containment failure due to a hydrogen burn) do not result in high individual doses at the reference site because of effective early phase protective actions. Only the relatively infrequent bypass events that exhibit low warning times coupled with large releases are likely to result in elevated doses at the reference site.

Table 4.3-9: Population-weighted individual latent fatality risk, 0–10 mi (mean value across all weather trials): HE_2

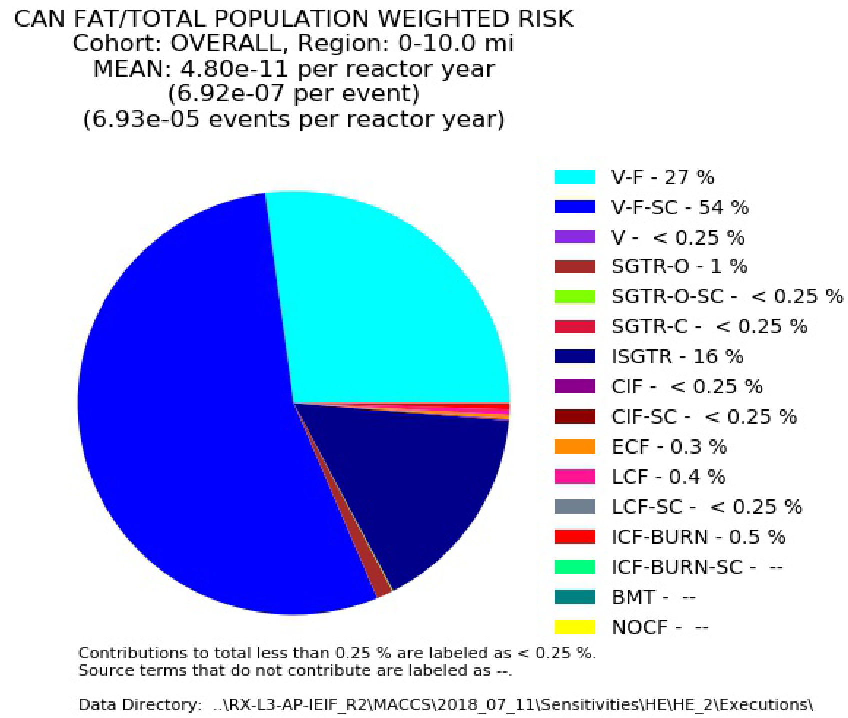
Release Category	Frequency (/rcy)	Reference Case (ME_2)	HE_2	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**2.5E-08**	**4.8E-11**	**0.002**
V-F	1.0E-07	4.7E-04	1.3E-04	0.278
V-F-SC	2.0E-07	3.6E-04	1.3E-04	0.366
V	7.0E-08	5.5E-05	6.1E-09	0.000
SGTR-O	7.0E-08	6.5E-04	8.5E-06	0.013
SGTR-O-SC	2.0E-07	1.3E-04	1.5E-07	0.001
SGTR-C	7.0E-08	2.1E-04	1.2E-07	0.001
ISGTR	6.0E-07	8.4E-04	1.3E-05	0.015
CIF	7.0E-08	8.0E-04	5.1E-07	0.001
CIF-SC	7.0E-08	6.0E-04	4.2E-07	0.001
ECF	7.0E-08	8.6E-04	2.1E-06	0.002
LCF	2.9E-05	6.1E-04	6.7E-09	0.000
LCF-SC	3.0E-06	1.5E-04	1.3E-10	0.000
ICF-BURN	9.0E-06	6.8E-04	2.6E-08	0.000
ICF-BURN-SC	2.0E-06	7.8E-06	-	-
BMT	8.0E-07	1.3E-05	-	-
NOCF	2.4E-05	1.4E-05	-	-

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



HE_2

Figure 4.3-12: Relative contribution of release categories to population-weighted individual latent fatality risk within 10 miles: HE_2

Table 4.3-10: Total latent fatality cases, 0–50 mi (mean value across all weather trials): HE_2

Release Category	Frequency (/rcy)	Reference Case (ME_2)	HE_2	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.1E-03**	**2.0E-05**	**0.004**
V-F	1.0E-07	2.0E+02	2.6E+01	0.133
V-F-SC	2.0E-07	1.5E+02	2.2E+01	0.145
V	7.0E-08	6.4E+00	1.9E-02	0.003
SGTR-O	7.0E-08	3.2E+02	1.8E+01	0.056
SGTR-O-SC	2.0E-07	3.5E+01	6.9E-02	0.002
SGTR-C	7.0E-08	5.8E+01	6.2E-02	0.001
ISGTR	6.0E-07	2.7E+02	6.1E+00	0.022
CIF	7.0E-08	2.2E+02	2.8E-01	0.001
CIF-SC	7.0E-08	1.8E+02	2.4E-01	0.001
ECF	7.0E-08	3.8E+02	2.6E+00	0.007
LCF	2.9E-05	9.6E+01	1.9E-01	0.002
LCF-SC	3.0E-06	1.5E+01	6.1E-02	0.004
ICF-BURN	9.0E-06	2.2E+02	1.8E-01	0.001
ICF-BURN-SC	2.0E-06	7.9E-01	5.3E-03	0.007
BMT	8.0E-07	1.4E+00	2.4E-03	0.002
NOCF	2.4E-05	1.3E+00	6.0E-03	0.005

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.3-11: Total latent fatality cases, 0–100 mi (mean value across all weather trials): HE_2

Release Category	Frequency (/rcy)	Reference Case (ME_2)	HE_2	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**1.0E-02**	**2.0E-05**	**0.002**
V-F	1.0E-07	5.1E+02	2.7E+01	0.053
V-F-SC	2.0E-07	4.0E+02	2.3E+01	0.058
V	7.0E-08	1.2E+01	1.9E-02	0.002
SGTR-O	7.0E-08	1.0E+03	1.8E+01	0.018
SGTR-O-SC	2.0E-07	7.1E+01	6.9E-02	0.001
SGTR-C	7.0E-08	1.1E+02	6.2E-02	0.001
ISGTR	6.0E-07	6.6E+02	6.4E+00	0.010
CIF	7.0E-08	4.1E+02	2.8E-01	0.001
CIF-SC	7.0E-08	3.4E+02	2.4E-01	0.001
ECF	7.0E-08	1.0E+03	2.6E+00	0.003
LCF	2.9E-05	1.8E+02	1.9E-01	0.001
LCF-SC	3.0E-06	2.8E+01	6.1E-02	0.002
ICF-BURN	9.0E-06	4.6E+02	1.8E-01	0.000
ICF-BURN-SC	2.0E-06	1.3E+00	5.3E-03	0.004
BMT	8.0E-07	2.3E+00	2.4E-03	0.001
NOCF	2.4E-05	2.1E+00	6.0E-03	0.003

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.4 Land Contamination

The extent of land contamination is examined in order to understand the contributors to projected economic losses. Land contamination may be characterized either in terms of how much land would exceed a specified radionuclide deposition level (MACCS Type D output, Table 4.4-1) or how much land is projected to be subject to different types of protective actions (MACCS Type 12 output, Tables 4.4-2 and 4.4-3). Examination of Table 4.4-1 shows that the absolute value of a land contamination measure based on Cs-137 deposition is sensitive to the deposition level chosen as a threshold. A level of 15 Ci/km^2 is chosen for further examination as that level is likely to require some level of restriction during the intermediate and recovery phases. As discussed in Annex I of (IAEA 2001), this value was chosen following the Chernobyl accident as a level at which the population was relocated. It should be noted that this does not imply that relocation would be projected in MACCS at this deposition level. This is simply chosen as a benchmark level of land contamination.

Table 4.4-1a: Mean (across all weather trials) land area (mi^2) exceeding specified Cs-137 deposition levels within 50 miles of the site

Release Category	Frequency (/rcy)	Cs-137 deposition > 1 Ci/km^2	Cs-137 deposition > 5 Ci/km^2	Cs-137 deposition > 15 Ci/km^2	Cs-137 deposition > 40 Ci/km^2
V-F	1.0E-07	1480	919	528	210
V-F-SC	2.0E-07	1130	743	371	142
V	7.0E-08	75	15	5	2
SGTR-O	7.0E-08	2540	1730	1230	770
SGTR-O-SC	2.0E-07	598	134	47	18
SGTR-C	7.0E-08	873	324	103	39
ISGTR	6.0E-07	2770	1440	792	348
CIF	7.0E-08	2660	851	283	104
CIF-SC	7.0E-08	1780	612	202	74
ECF	7.0E-08	3200	1680	986	464
LCF	2.9E-05	1070	199	63	22
LCF-SC	3.0E-06	166	32	10	3
ICF-BURN	9.0E-06	2390	640	206	77
ICF-BURN-SC	2.0E-06	8	1.5	0.5	0.16
BMT	8.0E-07	5	0.8	0.2	0.05
NOCF	2.4E-05	10	1.8	0.6	0.16

Table 4.4-1b: Mean (across all weather trials) land area (mi^2) exceeding specified Cs-137 deposition levels within 100 miles of the site

Release Category	Frequency (/rcy)	Cs-137 deposition > 1 Ci/km^2	Cs-137 deposition > 5 Ci/km^2	Cs-137 deposition > 15 Ci/km^2	Cs-137 deposition > 40 Ci/km^2
V-F	1.0E-07	4840	2290	760	255
V-F-SC	2.0E-07	3990	1660	501	172
V	7.0E-08	76	15	5	2
SGTR-O	7.0E-08	8180	5040	2620	1080
SGTR-O-SC	2.0E-07	972	158	49	18
SGTR-C	7.0E-08	1690	349	103	39
ISGTR	6.0E-07	7070	2780	1050	361
CIF	7.0E-08	4620	955	285	104
CIF-SC	7.0E-08	3180	687	204	74
ECF	7.0E-08	8540	3950	1540	516
LCF	2.9E-05	1110	199	63	22
LCF-SC	3.0E-06	166	32	10	3
ICF-BURN	9.0E-06	4220	690	207	77
ICF-BURN-SC	2.0E-06	8	2	0.5	0.16
BMT	8.0E-07	5	1	0.2	0.05
NOCF	2.4E-05	10	2	0.6	0.16

Table 4.4-2 shows the areal extent of agricultural restrictions that would be expected in the year of the accident, such as crop or milk disposal, as well as longer term restrictions, such as interdiction or condemnation. Values are given for the mean affected areas within 100 miles. Examination of Table 4.4-2 shows the areal extent of agricultural restrictions is likely to be the highest in the year of the accident, although some level of interdiction may be necessary in following years. However, comparison of the interdicted to condemned land shows that the majority of land initially subject to agricultural restrictions may eventually be recovered as natural weathering and radioactive decay reduce doses to levels below the interdiction criteria. It should be noted that the agricultural interdiction criteria used in this analysis (DOSEMILK, DOSEOTHER, and DOSELONG) are set low enough to ensure that the more restrictive child dose levels are not exceeded. All else being equal, more restrictive agricultural interdiction criteria will reduce collective doses from ingestion, but will result in larger areas projected to be subject to agricultural restrictions. Also of interest is the fact that no farmland is projected to be decontaminated in this analysis. This is believed to be due to updated decontamination cost parameters (CDFRM) that include the cost of waste disposal. The high disposal costs associated with removal and disposal of contaminated farmland soil, coupled with the relatively low per hectare value of farmland (VFRM), may cause the MACCS code to project condemnation or interdiction rather than decontamination efforts on farmland because the cost of decontamination would exceed the property value of the land.

Table 4.4-2: Mean (across all weather trials) land area (mi^2) within 100 miles subject to agricultural restrictions

Release Category	Freq. (/rcy)	Crop Disposal	Milk Disposal	Farmland Decon.	Farmland Interdiction	Farmland Condemn.
V-F	1.0E-07	1470	1950	-	1350	121
V-F-SC	2.0E-07	1210	1640	-	1130	80
V	7.0E-08	75	399	-	73	2
SGTR-O	7.0E-08	2520	3540	-	2040	477
SGTR-O-SC	2.0E-07	507	811	-	498	8
SGTR-C	7.0E-08	710	1330	-	692	18
ISGTR	6.0E-07	3110	4860	-	2940	173
CIF	7.0E-08	2110	3720	-	2060	51
CIF-SC	7.0E-08	1470	3010	-	1430	36
ECF	7.0E-08	3120	4370	-	2870	252
LCF	2.9E-05	941	2420	-	930	11
LCF-SC	3.0E-06	104	192	-	101	3
ICF-BURN	9.0E-06	2050	3360	-	2010	37
ICF-BURN-SC	2.0E-06	6	25	-	6	0.12
BMT	8.0E-07	4	19	-	4	0.04
NOCF	2.4E-05	7	28	-	7	0.16

Note: Freq.: Frequency; Decon.: Decontamination; Condemn.: Condemnation

Table 4.4-3 shows the areal extent of population restrictions, such as interdiction or condemnation, that may be needed following the accident. Examination of the values in Table 4.4-2 and Table 4.4-3 suggest that (1) population restrictions would be less widespread than agricultural restrictions, and (2) long-term restrictions, such as condemnation, would be less widespread than temporary restrictions that allow for decontamination, weathering, and radioactive decay to reduce doses to levels allowing habitation.

Table 4.4-3: Mean (across all weather trials) land area (mi^2) within 100 miles subject to population restrictions

Release Category	Frequency (/rcy)	Non-Farmland Decontamination/ Interdiction	Non-Farmland Condemnation
V-F	1.0E-07	330	2.5
V-F-SC	2.0E-07	220	1.7
V	7.0E-08	3.9	0.03
SGTR-O	7.0E-08	1300	11.3
SGTR-O-SC	2.0E-07	21	0.05
SGTR-C	7.0E-08	46	0.5
ISGTR	6.0E-07	470	4.4
CIF	7.0E-08	240	1.3
CIF-SC	7.0E-08	220	0.9
ECF	7.0E-08	1100	5.6
LCF	2.9E-05	93	0.2
LCF-SC	3.0E-06	8.5	0.03
ICF-BURN	9.0E-06	380	0.7
ICF-BURN-SC	2.0E-06	0.48	-
BMT	8.0E-07	0.65	-
NOCF	2.4E-05	0.94	-

The contributions of the different release categories, considering both their frequency and their conditional consequences, are shown in Figure 4.4-1. The figure of merit selected for more detailed examination is the area within 50 miles (Figure 4.4-1a) and 100 miles (Figure 4.4-1b) exceeding a deposition level of 15 Ci/km^2 (555 kBq/m^2), because the initial Cs-137 deposition level drives the potential dose, and therefore the extent of protective actions. The relative contributions of release categories to the mean value for this figure of merit are similar to the relative contributions of release categories to the mean cesium and iodine release fractions shown in Figures 3.1-1 and 3.1-2, and are dominated by the LCF, ICF-BURN, and ISGTR release categories. This observation suggests that the magnitude of the cesium release fraction is important in determining the extent of land contamination.

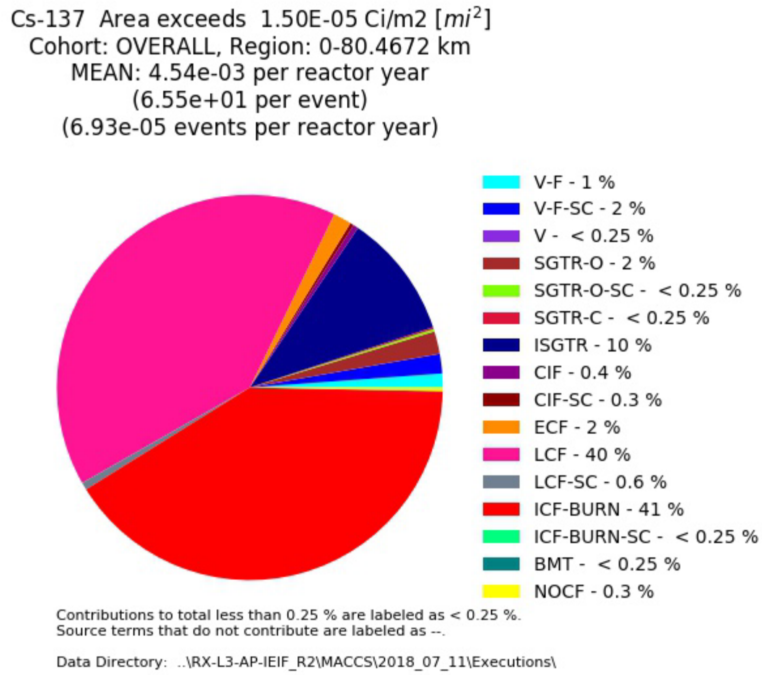


Figure 4.4-1a: Relative contribution of release categories to the frequency-weighted mean value of land area (mi²) exceeding a Cs-137 deposition of 15 Ci/km² (555 kBq/m²) within 50 miles

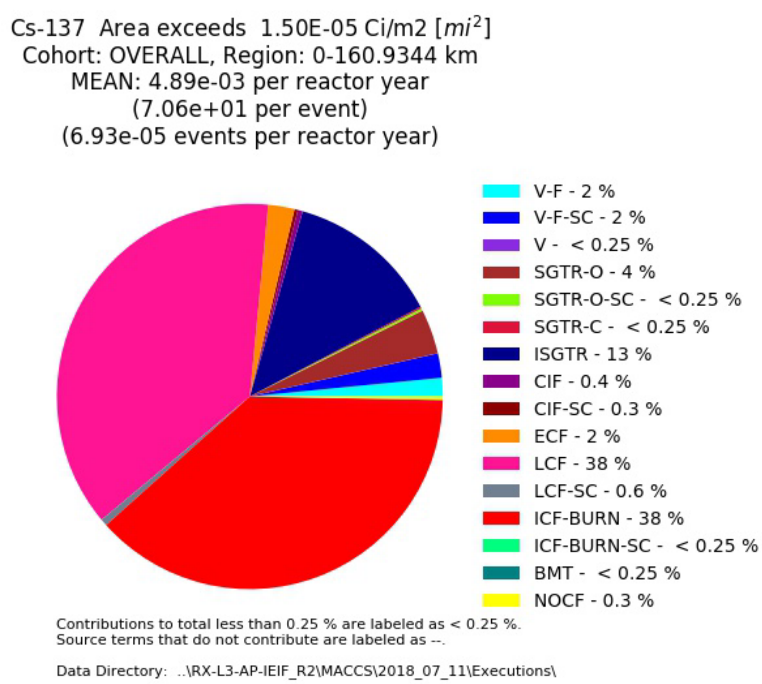


Figure 4.4-1b: Relative contribution of release categories to the frequency-weighted mean value of land area (mi²) exceeding a Cs-137 deposition of 15 Ci/km² (555 kBq/m²) within 100 miles

The importance of the release magnitude may be observed in Figure 4.4-2, showing the relationship between the cesium release fraction and the mean area subject to two different threshold levels of Cs-137 deposition. Inspection of this plot suggests that land contamination increases with the magnitude of the release, and that (for a given release) higher levels of deposition (e.g., 40 Ci/km^2 [1.5 MBq/m^2] versus 15 Ci/km^2 [555 kBq/m^2]) will occur over smaller areas.

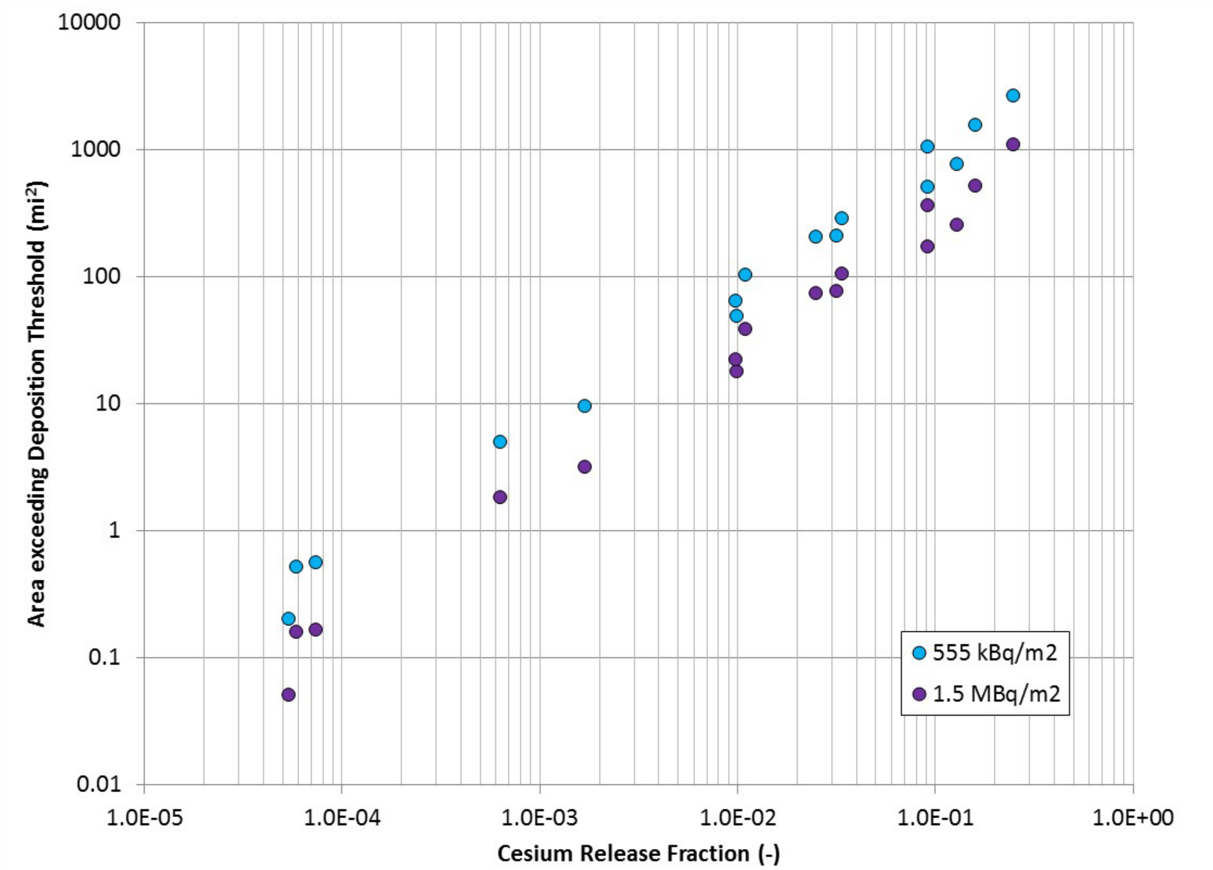


Figure 4.4-2: Mean (across all weather trials) land area (mi^2) within 100 miles exceeding a Cs-137 deposition of 40 Ci/km^2 (1.5 MBq/m^2) and 15 Ci/km^2 (555 kBq/m^2) as a function of cesium release fraction

The relative contribution of different weather bins and release categories to the mean value of the area exceeding a deposition level of 15 Ci/km^2 within 50 and 100 miles is shown in Figure 4.4-3a and Figure 4.4-3b, respectively. The stacked bar on the left shows the relative contribution to the mean for a particular weather bin from each release category. The solid blue bar to the right shows the relative frequency of the weather bin. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. These figures suggest that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value. This suggests that this result may not be particularly sensitive to the selection of alternate weather years, because there do not appear to be weather conditions that contribute disproportionately to the mean value. The contributions of individual release categories shown in Figure 4.4-3a and Figure 4.4-3b, dominated by the contributions from the ICF-BURN, LCF, and ISGTR release categories, are consistent with Figure 4.4-1a and Figure 4.4-1b.

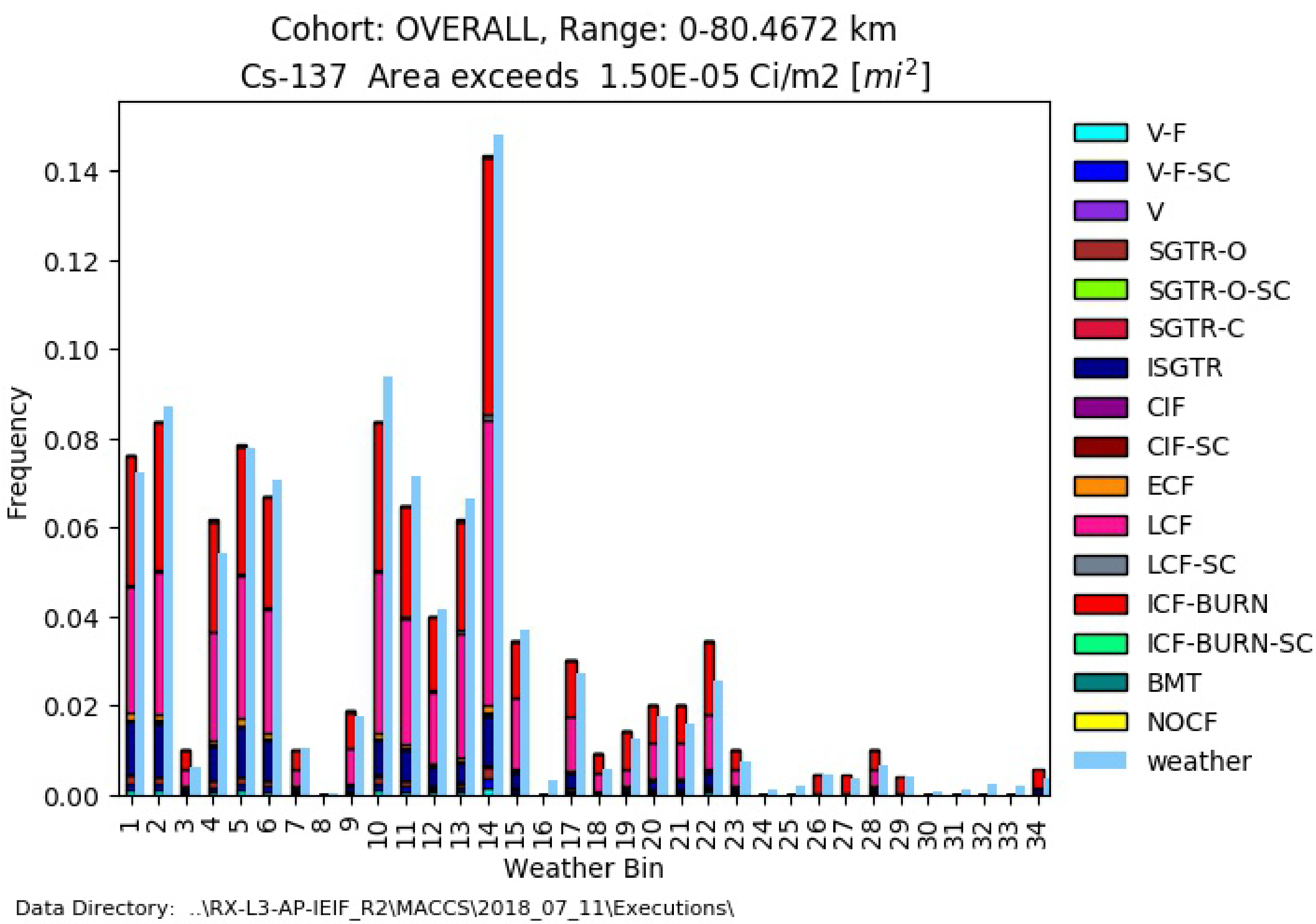


Figure 4.4-3a: Relative contribution of weather bins and release categories to frequency-weighted mean (across all weather trials) land area (mi^2) exceeding a Cs-137 deposition of 15 Ci/km^2 (555 kBq/m^2) within 50 miles

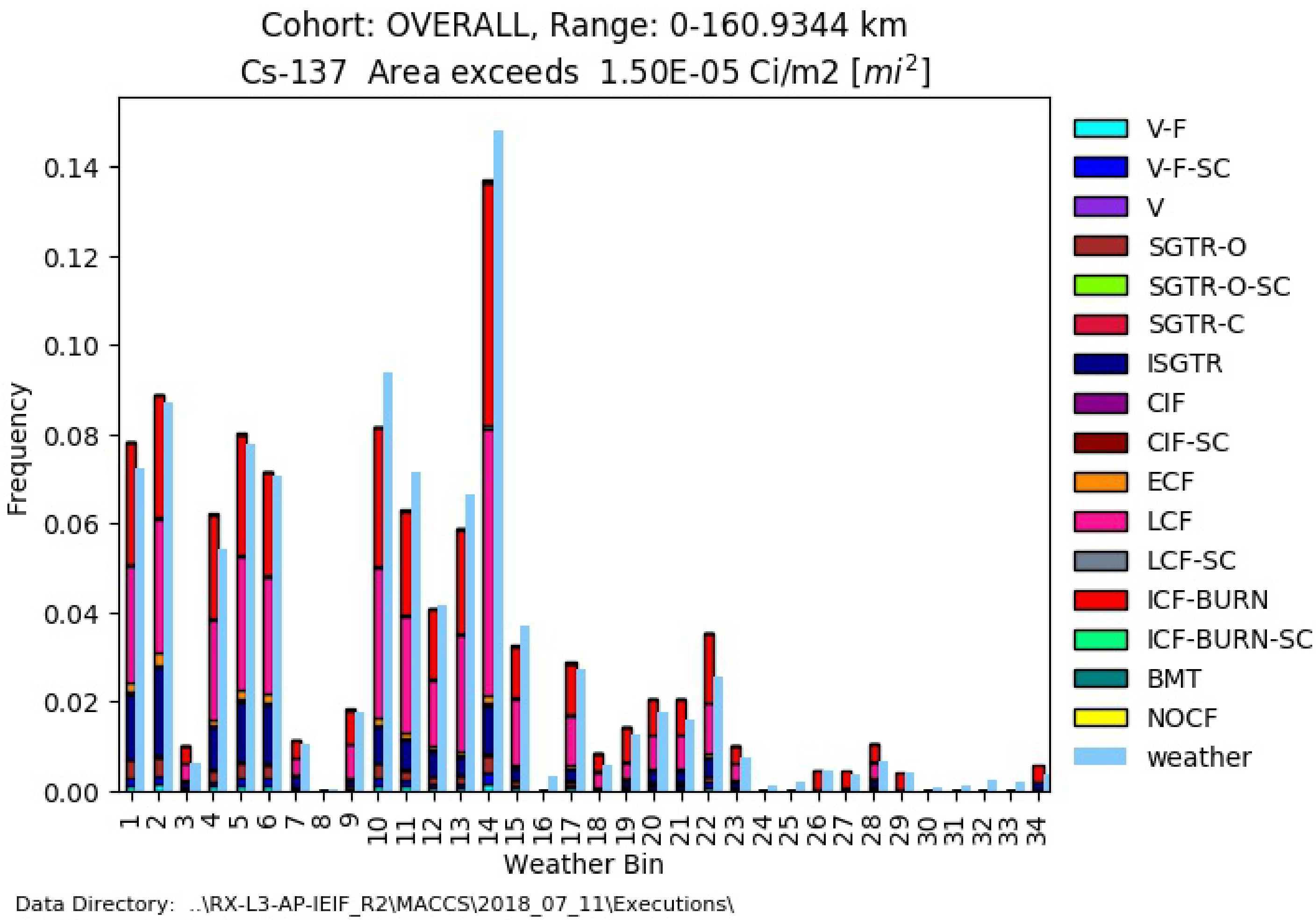


Figure 4.4-3b: Relative contribution of weather bins and release categories to frequency-weighted mean (across all weather trials) land area (mi²) exceeding a Cs-137 deposition of 15 Ci/km² (555 kBq/m²) within 100 miles

The complementary cumulative distribution functions of the area within 50 and 100 miles exceeding a deposition level of 15 Ci/km^2 (555 kBq/m^2) are shown in Figure 4.4-4a and Figure 4.4-4b, respectively. The results shown here are consistent with the results seen in Figures 4.4-1 through 4.4-3; namely, that the risk of land contamination is largely driven by the LCF, ICF-BURN, and ISGTR release categories. This is very similar to the relative contribution of release categories to other aggregate impacts (such as total latent cancer fatality cases or individual latent cancer fatality risk), as well as to the contributions to the mean cesium release fraction and mean iodine release fraction.

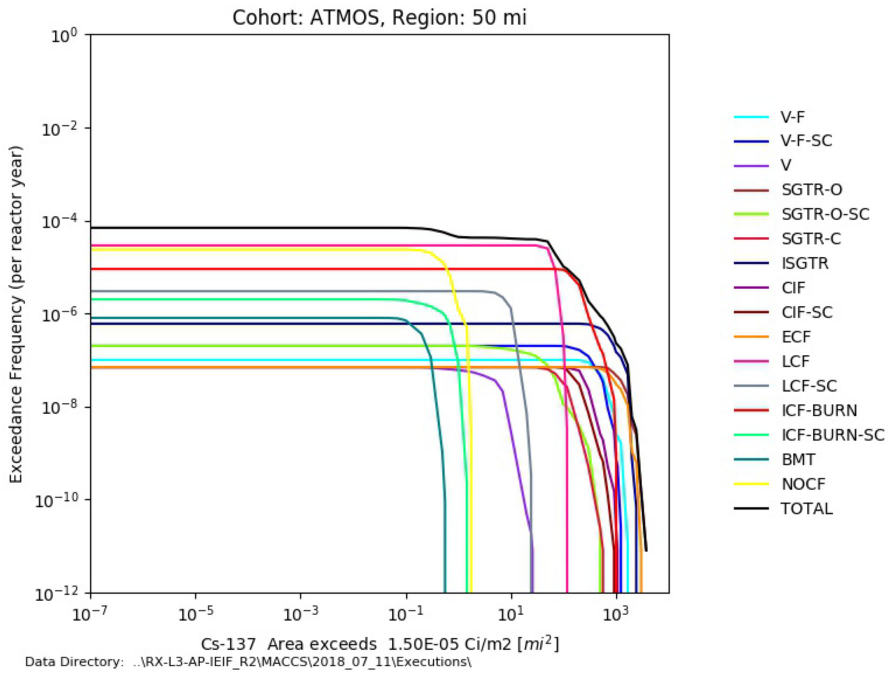


Figure 4.4-4a: Complementary cumulative distribution function, land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137 within 50 miles

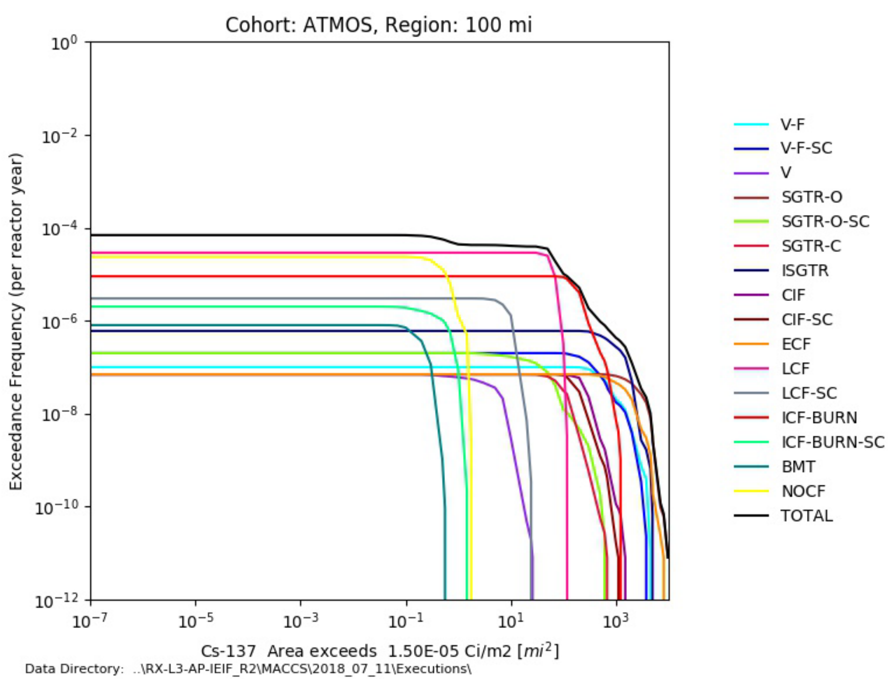


Figure 4.4-4b: Complementary cumulative distribution function, land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137 within 100 miles

4.4.1 Sensitivity Cases

4.4.1.1 *Meteorological Sampling*

The effect of sampling only a subset of the meteorological data on the land area exceeding 555 kBq/m^2 (15 Ci/km^2) within 50 and 100 miles is demonstrated in Table 4.4-4 and Table 4.4-5. It is evident from inspection of these results that differences resulting from sampling a representative subset of weather trials as opposed to sampling all 8760 hourly observations are generally less than a few percent.

Table 4.4-4: Land area (mi^2) exceeding 555 kBq/m^2 (15 Ci/km^2) Cs-137, 0–50 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**4.5E-03**	**4.6E-03**	**1.005**
V-F	1.0E-07	5.3E+02	5.4E+02	1.017
V-F-SC	2.0E-07	3.7E+02	3.8E+02	1.027
V	7.0E-08	5.0E+00	4.9E+00	0.994
SGTR-O	7.0E-08	1.2E+03	1.2E+03	1.000
SGTR-O-SC	2.0E-07	4.7E+01	4.8E+01	1.017
SGTR-C	7.0E-08	1.0E+02	1.1E+02	1.019
ISGTR	6.0E-07	7.9E+02	8.0E+02	1.005
CIF	7.0E-08	2.8E+02	2.9E+02	1.011
CIF-SC	7.0E-08	2.0E+02	2.1E+02	1.015
ECF	7.0E-08	9.9E+02	9.9E+02	1.002
LCF	2.9E-05	6.3E+01	6.3E+01	1.000
LCF-SC	3.0E-06	9.5E+00	9.7E+00	1.015
ICF-BURN	9.0E-06	2.1E+02	2.1E+02	1.010
ICF-BURN-SC	2.0E-06	5.1E-01	5.1E-01	0.992
BMT	8.0E-07	2.0E-01	2.0E-01	1.005
NOCF	2.4E-05	5.5E-01	5.4E-01	0.982

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.4-5: Land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137, 0–100 mi (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**4.9E-03**	**4.9E-03**	**1.005**
V-F	1.0E-07	7.6E+02	7.6E+02	0.995
V-F-SC	2.0E-07	5.0E+02	5.0E+02	0.994
V	7.0E-08	5.0E+00	4.9E+00	0.994
SGTR-O	7.0E-08	2.6E+03	2.6E+03	1.000
SGTR-O-SC	2.0E-07	4.9E+01	4.9E+01	1.014
SGTR-C	7.0E-08	1.0E+02	1.1E+02	1.019
ISGTR	6.0E-07	1.1E+03	1.1E+03	1.010
CIF	7.0E-08	2.9E+02	2.9E+02	1.011
CIF-SC	7.0E-08	2.0E+02	2.1E+02	1.015
ECF	7.0E-08	1.5E+03	1.5E+03	0.994
LCF	2.9E-05	6.3E+01	6.3E+01	1.000
LCF-SC	3.0E-06	9.5E+00	9.7E+00	1.015
ICF-BURN	9.0E-06	2.1E+02	2.1E+02	1.010
ICF-BURN-SC	2.0E-06	5.1E-01	5.1E-01	0.992
BMT	8.0E-07	2.0E-01	2.0E-01	1.005
NOCF	2.4E-05	5.5E-01	5.4E-01	0.982

1. Results are a frequency-weighted sum of all release categories
2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.4.1.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on the area (mi^2) exceeding 555 kBq/m^2 (15 Ci/km^2) Cs-137 within 50 and 100 miles is demonstrated in Tables 4.4-6 and 4.4-7. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

The effect of terminating the release is a reduction in contaminated land. On a frequency-weighted basis, the reduction is approximately a factor of two. It can be seen that some release categories (such as ISLOCA or SGTR release categories) are relatively unaffected with a reduction on the order of a few percent, whereas other release categories (such as the late containment failure (LCF) release category) are reduced by almost 99%.

The differential impact of the accident termination time on the relative contribution of release categories to the area (mi^2) exceeding 555 kBq/m^2 (15 Ci/km^2) Cs-137 within 50 and 100 miles is illustrated in Figures 4.4-5 and 4.4-6, respectively. The frequency weighted reduction in the extent of land contamination is a combination of the much lower conditional consequences for

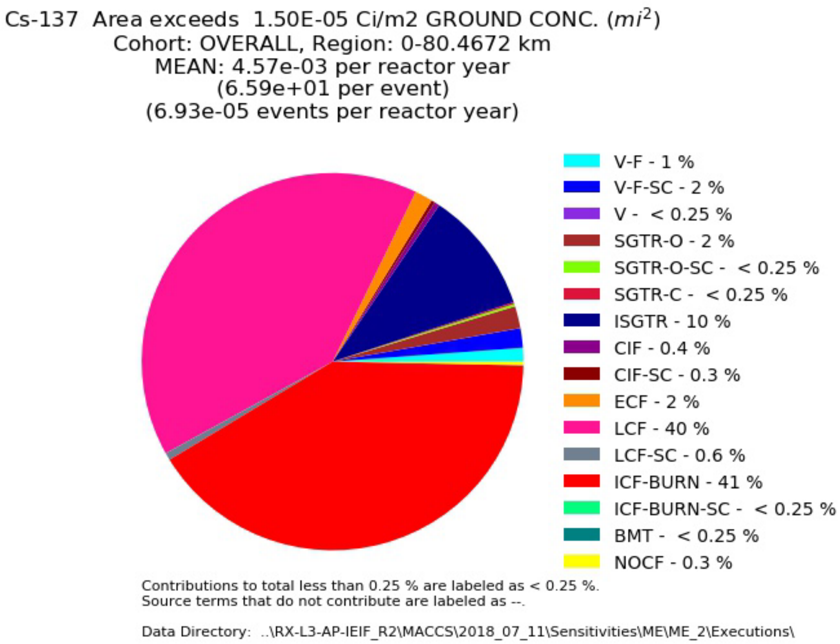
the LCF release category with a reduction in the conditional consequences for the ICF-BURN release category. The relative contribution of release categories to the extent of contaminated land is similar to the relative contribution of release categories to the cumulative cesium release shown in Figure 5-1, with the ICF-BURN and ISGTR release categories increasing in relative importance and the LCF release category comprising a much smaller contributor.

Table 4.4-6: Land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137, 0–50 mi (mean value across all weather trials): RE_4

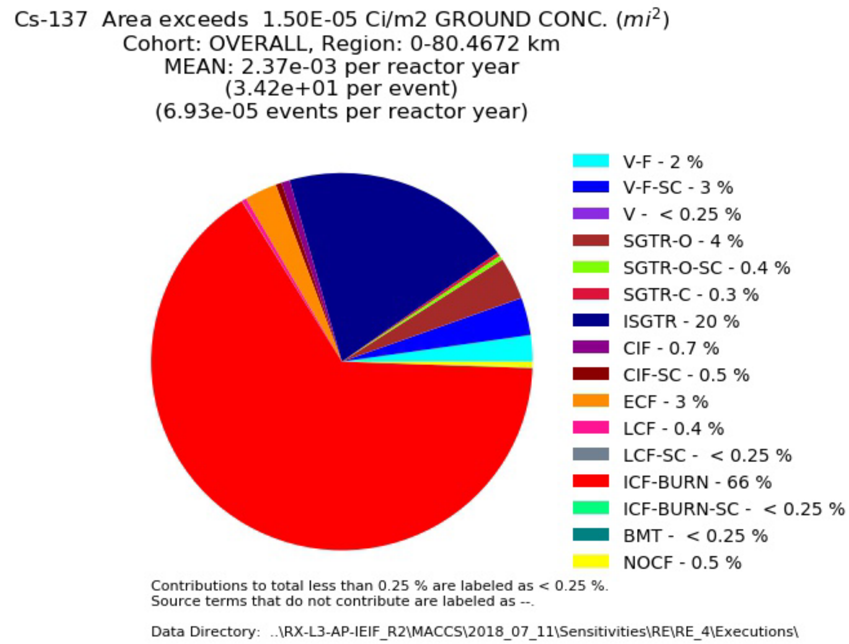
Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**4.6E-03**	**2.4E-03**	**0.519**
V-F	1.0E-07	5.4E+02	5.4E+02	1.000
V-F-SC	2.0E-07	3.8E+02	3.8E+02	1.000
V	7.0E-08	4.9E+00	4.9E+00	1.000
SGTR-O	7.0E-08	1.2E+03	1.2E+03	0.992
SGTR-O-SC	2.0E-07	4.8E+01	4.8E+01	1.000
SGTR-C	7.0E-08	1.1E+02	1.0E+02	0.981
ISGTR	6.0E-07	8.0E+02	7.8E+02	0.975
CIF	7.0E-08	2.9E+02	2.4E+02	0.825
CIF-SC	7.0E-08	2.1E+02	1.7E+02	0.849
ECF	7.0E-08	9.9E+02	9.3E+02	0.944
LCF	2.9E-05	6.3E+01	3.1E-01	0.005
LCF-SC	3.0E-06	9.7E+00	2.9E-01	0.030
ICF-BURN	9.0E-06	2.1E+02	1.7E+02	0.832
ICF-BURN-SC	2.0E-06	5.1E-01	5.1E-01	1.000
BMT	8.0E-07	2.0E-01	1.7E-01	0.841
NOCF	2.4E-05	5.4E-01	4.9E-01	0.904

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



RE_4

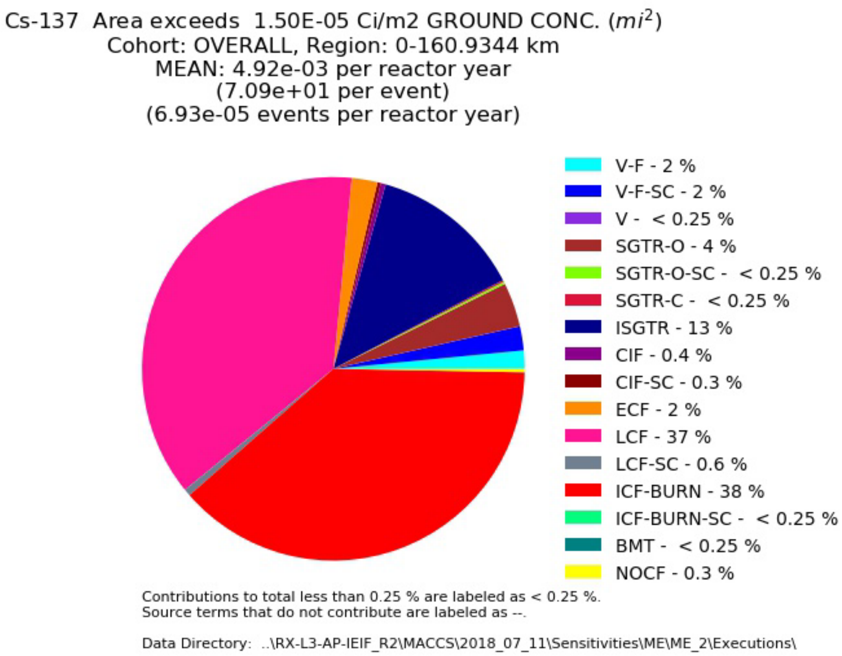
Figure 4.4-5: Relative contribution of release categories to land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137, 0–50 mi: RE_4

Table 4.4-7: Land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137, 0–100 mi (mean value across all weather trials): RE_4

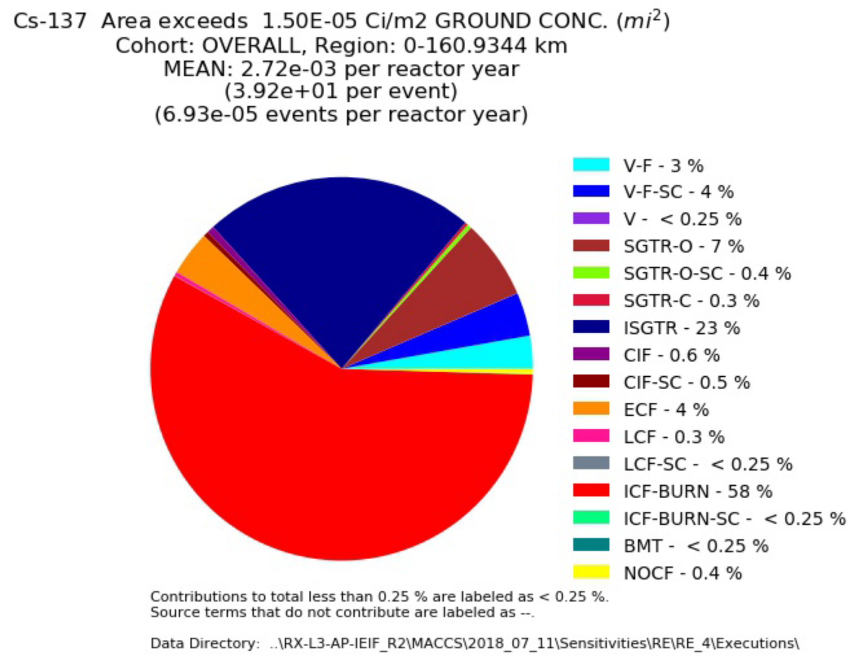
Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**4.9E-03**	**2.7E-03**	**0.553**
V-F	1.0E-07	7.6E+02	7.6E+02	1.000
V-F-SC	2.0E-07	5.0E+02	5.0E+02	1.000
V	7.0E-08	4.9E+00	4.9E+00	1.000
SGTR-O	7.0E-08	2.6E+03	2.6E+03	0.996
SGTR-O-SC	2.0E-07	4.9E+01	4.9E+01	1.000
SGTR-C	7.0E-08	1.1E+02	1.0E+02	0.990
ISGTR	6.0E-07	1.1E+03	1.0E+03	0.981
CIF	7.0E-08	2.9E+02	2.4E+02	0.823
CIF-SC	7.0E-08	2.1E+02	1.8E+02	0.850
ECF	7.0E-08	1.5E+03	1.5E+03	0.961
LCF	2.9E-05	6.3E+01	3.1E-01	0.005
LCF-SC	3.0E-06	9.7E+00	2.9E-01	0.030
ICF-BURN	9.0E-06	2.1E+02	1.7E+02	0.833
ICF-BURN-SC	2.0E-06	5.1E-01	5.1E-01	1.000
BMT	8.0E-07	2.0E-01	1.7E-01	0.841
NOCF	2.4E-05	5.4E-01	4.9E-01	0.904

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



RE_4

Figure 4.4-6: Relative contribution of the individual release categories to land area (mi^2) exceeding 15 Ci/km^2 (555 kBq/m^2) Cs-137, 0–100 mi: RE_4

4.4.1.3 *Low-Dose Cancer Risk Estimation*

Inspection of the results for estimated land contamination results arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem), shows that (as expected) there is no difference between the results of the reference case and the results for sensitivity case HE-2. For this sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of using a dose truncation model. The ratio of the results of the reference and sensitivity case were 1.000 for all release categories and are therefore not reproduced here.

4.5 Affected Population

The size of the affected population in a MACCS calculation is a function of the time period of interest. Using the Type 14 output, MACCS can report the number of people affected by different (1) early-phase actions (which would last on the order of days), (2) intermediate-phase actions (which may last up to a year in MACCS 3.10), (3) decontamination efforts (which, in MACCS 3.10, may extend for up to a year beyond the intermediate phase, for a total of up to 2 years following the accident), and (4) longer term actions, such as longer term interdiction following decontamination, or condemnation if decontamination is unable to reduce doses to habitability criteria. The specific outputs are as follows:

- EVACUEES NOT AFFECTED BY PLUME[46]—the number of evacuees whose property is not contaminated and can return during or immediately after the emergency phase
- EVACUEES AFFECTED BY PLUME—the number of evacuees whose property is contaminated and may not be able to return during or immediately after the emergency phase
- NORMAL EMERGENCY PHASE RELOCATION—the number of relocatees who are affected by normal relocation during the emergency phase
- HOTSPOT EMERGENCY PHASE RELOCATION—the number of relocatees who are affected by hotspot relocation during the emergency phase
- INTERMEDIATE PHASE RELOCATION—the number of relocatees during the intermediate phase
- LEVEL 1 DECONTAMINATION RELOCATION—the number of people whose property requires the first level of decontamination during the long-term phase
- LEVEL 2 DECONTAMINATION RELOCATION—the number of people whose property requires the second level of decontamination during the long-term phase
- LEVEL 3 DECONTAMINATION RELOCATION—the number of people whose property requires the third level of decontamination during the long-term phase, but can return immediately after the decontamination is completed
- DECONTAMINATION+INTERDICTION RELOC—the number of people whose property requires the highest level of decontamination (depending on the number of levels specified in the input) plus additional interdiction following the decontamination
- CONDEMNATION RELOCATION—the number of people whose property is condemned

The mean size of the population within 50 and 100 miles subject to early-phase protective actions is shown by release category in Tables 4.5-1 and 4.5-2, respectively. The mean size of the population subject to intermediate- and recovery-phase protective actions is shown by release category for these same distances in Tables 4.5-3 and 4.5-4, respectively.

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[46] Shortly before completion of this document, a potential error in the Type 14 output for the number of evacuees not affected by the plume for cohorts modeled with a keyhole evacuation was identified. That detailed output metric value is therefore not tabulated in this report.

Table 4.5-1: Mean (Across all weather trials) size of population within 50 miles subject to early-phase protective actions

Release Category	Frequency (/rcy)	Evacuees Affected By Plume	Hotspot Relocation	Normal Relocation
V-F	1.0E-07	58000	8300	45000
V-F-SC	2.0E-07	58000	7200	40000
V	7.0E-08	13000	0.01	1
SGTR-O	7.0E-08	67000	8400	62000
SGTR-O-SC	2.0E-07	27000	0.4	170
SGTR-C	7.0E-08	65000	0.3	20
ISGTR	6.0E-07	69000	2600	52000
CIF	7.0E-08	69000	1.5	1500
CIF-SC	7.0E-08	69000	1.4	1200
ECF	7.0E-08	67000	320	30000
LCF	2.9E-05	31000	0.2	57
LCF-SC	3.0E-06	15000	-	0.00009
ICF-BURN	9.0E-06	66000	2.3	2100
ICF-BURN-SC	2.0E-06	3300	-	0.0003
BMT	8.0E-07	16000	-	0.0006
NOCF	2.4E-05	16000	-	-

Table 4.5-2: Mean (across all weather trials) size of population within 100 miles subject to early-phase protective actions

Release Category	Frequency (/rcy)	Evacuees Affected By Plume	Hotspot Relocation	Normal Relocation
V-F	1.0E-07	58000	8300	59000
V-F-SC	2.0E-07	58000	7200	49000
V	7.0E-08	13000	0.01	1
SGTR-O	7.0E-08	67000	8400	82000
SGTR-O-SC	2.0E-07	27000	0.4	170
SGTR-C	7.0E-08	65000	0.3	20
ISGTR	6.0E-07	69000	2600	57000
CIF	7.0E-08	69000	1.5	1500
CIF-SC	7.0E-08	69000	1.4	1200
ECF	7.0E-08	67000	320	30000
LCF	2.9E-05	31000	0.2	57
LCF-SC	3.0E-06	15000	-	0.00009
ICF-BURN	9.0E-06	66000	2.3	2100
ICF-BURN-SC	2.0E-06	3300	-	0.0003
BMT	8.0E-07	16000	-	0.0006
NOCF	2.4E-05	16000	-	-

Table 4.5-3: Mean (across all weather trials) size of population within 50 miles subject to intermediate- and recovery-phase protective actions

Release Category	Frequency (/rcy)	Intermediate-Phase Relocation	Level 1 Decon	Level 2 Decon	Level 3 Decon	Decon+ Interdiction	Condemnation
V-F	1.0E-07	27000	29000	3400	2300	630	37
V-F-SC	2.0E-07	18000	21000	2000	1600	420	20
V	7.0E-08	9.1	38	1	0.7	0.04	-
SGTR-O	7.0E-08	78000	61000	15000	14000	2500	310
SGTR-O-SC	2.0E-07	1100	1600	93	41	3.5	0.04
SGTR-C	7.0E-08	1800	2800	180	110	15	1.3
ISGTR	6.0E-07	37000	42000	4100	2400	510	36
CIF	7.0E-08	17000	7100	360	190	27	2.1
CIF-SC	7.0E-08	16000	5400	280	140	21	1.8
ECF	7.0E-08	93000	52000	6500	4200	870	61
LCF	2.9E-05	4000	250	12	6.6	0.1	-
LCF-SC	3.0E-06	16	52	1.2	0.4	-	-
ICF-BURN	9.0E-06	39000	4600	230	110	15	0.7
ICF-BURN-SC	2.0E-06	0.1	0.8	-	-	-	-
BMT	8.0E-07	0.4	0.1	-	-	-	-
NOCF	2.4E-05	0.8	1.2	-	-	-	-

Note: Decon: Decontamination

Table 4.5-4: Mean (across all weather trials) size of population within 100 miles subject to intermediate- and recovery-phase protective actions

Release Category	Frequency (/rcy)	Intermediate-Phase Relocation	Level 1 Decon	Level 2 Decon	Level 3 Decon	Decon+ Interdiction	Condemnation
V-F	1.0E-07	33000	39000	3900	2500	630	37
V-F-SC	2.0E-07	23000	28000	2300	1700	420	20
V	7.0E-08	9.1	38	1	0.7	0.04	-
SGTR-O	7.0E-08	120000	140000	16000	14000	2500	310
SGTR-O-SC	2.0E-07	1100	1600	93	41	3.5	0.04
SGTR-C	7.0E-08	1800	2800	180	110	15	1.3
ISGTR	6.0E-07	40000	48000	4100	2400	510	36
CIF	7.0E-08	17000	7100	360	190	27	2.1
CIF-SC	7.0E-08	16000	5400	280	140	21	1.8
ECF	7.0E-08	110000	72000	6800	4200	870	61
LCF	2.9E-05	4000	250	12	6.6	0.1	-
LCF-SC	3.0E-06	16	52	1.2	0.4	-	-
ICF-BURN	9.0E-06	40000	4700	230	110	15	0.7
ICF-BURN-SC	2.0E-06	0.1	0.8	-	-	-	-
BMT	8.0E-07	0.4	0.1	-	-	-	-
NOCF	2.4E-05	0.8	1.2	-	-	-	-

Note: Decon: Decontamination

A few observations may be drawn from these tables:

- Early-phase protective actions are largely confined to the area within 50 miles of the site. Although some of the population beyond 50 miles may be projected to receive doses >1 rem in 4 days, none of the population (on average) beyond 50 miles is projected to exceed the upper (5 rem) PAG limit associated with MACCS hotspot relocation.
- The size of the affected population drops as a function of the time since the accident; that is, the populations most likely to be affected are those within 20 miles of the plant that are subject to preemptive evacuation. The size of the population subject to intermediate-phase relocation and level 1 decontamination (i.e., projected to receive a dose greater than 2 rem in the year of the accident, and greater than 500 mrem in the year after the accident) is generally smaller than the early-phase evacuation and relocation population. The only exceptions are the low frequency SGTR-O and ECF release categories, which have the largest Cs release fractions.
- The majority of the affected population in the late (recovery) phase is due to those requiring a relatively limited level of decontamination (no more than a decontamination factor [DF] of 3). The size of the population requiring more extensive protective actions (Level 2 and Level 3 decontamination with DF>3, decontamination followed by interdiction, or condemnation) is, on average, much smaller.

The contributions of individual release categories to the mean value of population subject to early-, intermediate-, and late/recovery-phase protective actions are shown in Figures 4.5-1 through 4.5-4. Figure 4.5-1 shows the contributions of individual release categories to the mean value of population subject to early-phase protective actions within 100 miles. The figure of merit used to generate this curve is the sum of the evacuees affected by the plume and the size of the population subject to either hotspot or normal early-phase relocation. Figure 4.5-2 shows the contribution of release categories to the mean value of the combined intermediate and late phase affected population within 100 miles. Figures 4.5-3 and 4.5-4 show the contribution of release categories to the mean value of the intermediate phase affected population within 50 and 100 miles, respectively. A clear distinction between the drivers of the population affected by early-phase actions versus intermediate-phase actions is evident. The contribution of release categories to the mean size of the early-phase affected population (shown in Figure 4.5-1) has a sizable contribution from the relatively higher frequency, lower consequence NOCF release category, because that case is modeled with a full evacuation of the 10-mile EPZ, the industrial facility, and a 5-mile shadow evacuation outside the EPZ. In contrast, the relative contribution of release categories to the size of the population subject to intermediate-phase relocation (shown in Figures 4.5-3 and 4.5-4) is much more similar to the contributors to the mean cesium release fraction shown in Figure 3.1-1, and are dominated by the LCF and ICF-BURN release categories.

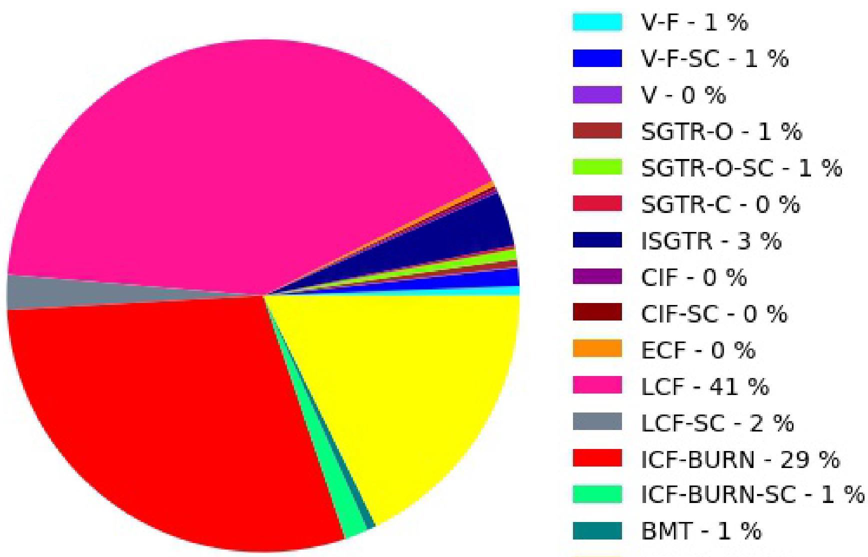


Figure 4.5-1: Contribution of release categories to early-phase affected population size within 100 miles

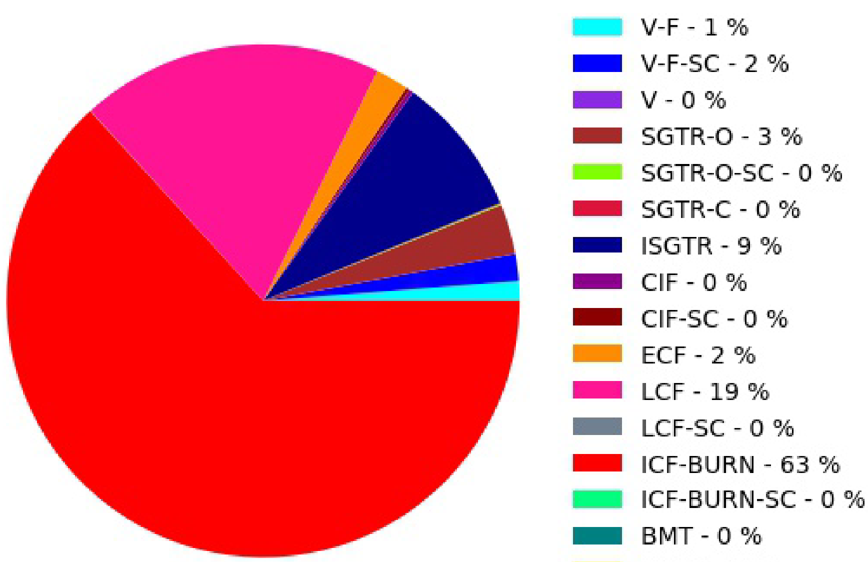


Figure 4.5-2: Contribution of release categories to combined intermediate- and late-phase affected population size within 100 miles

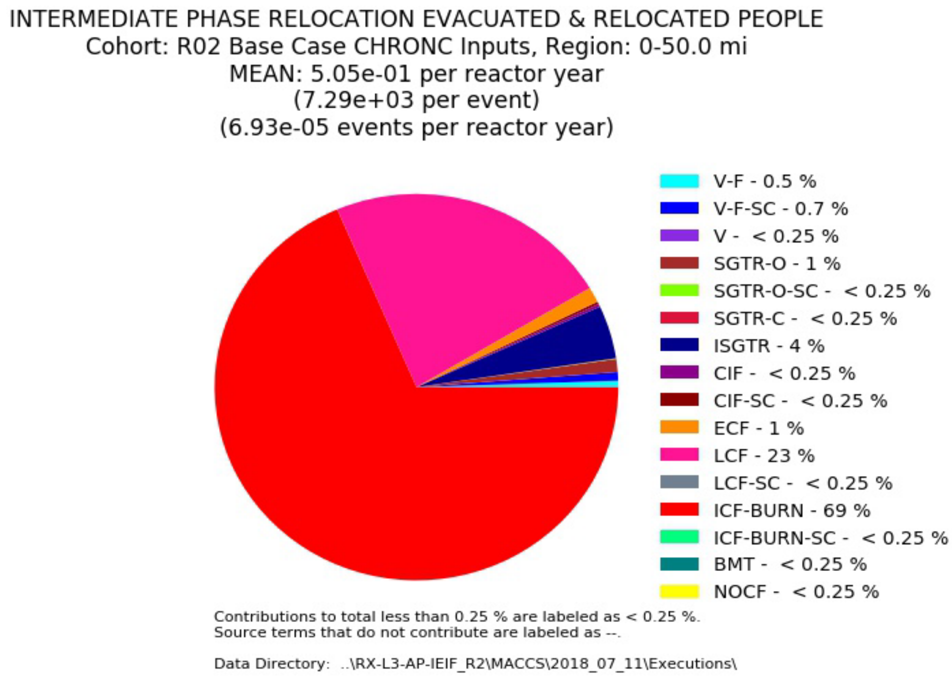


Figure 4.5-3: Contribution of release categories to intermediate-phase affected population size within 50 miles

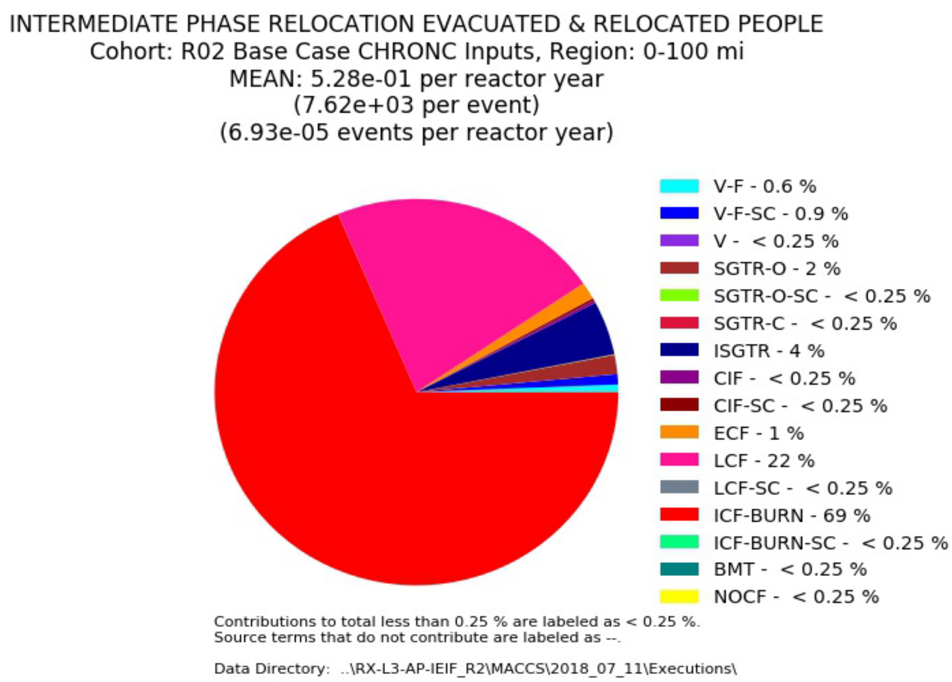
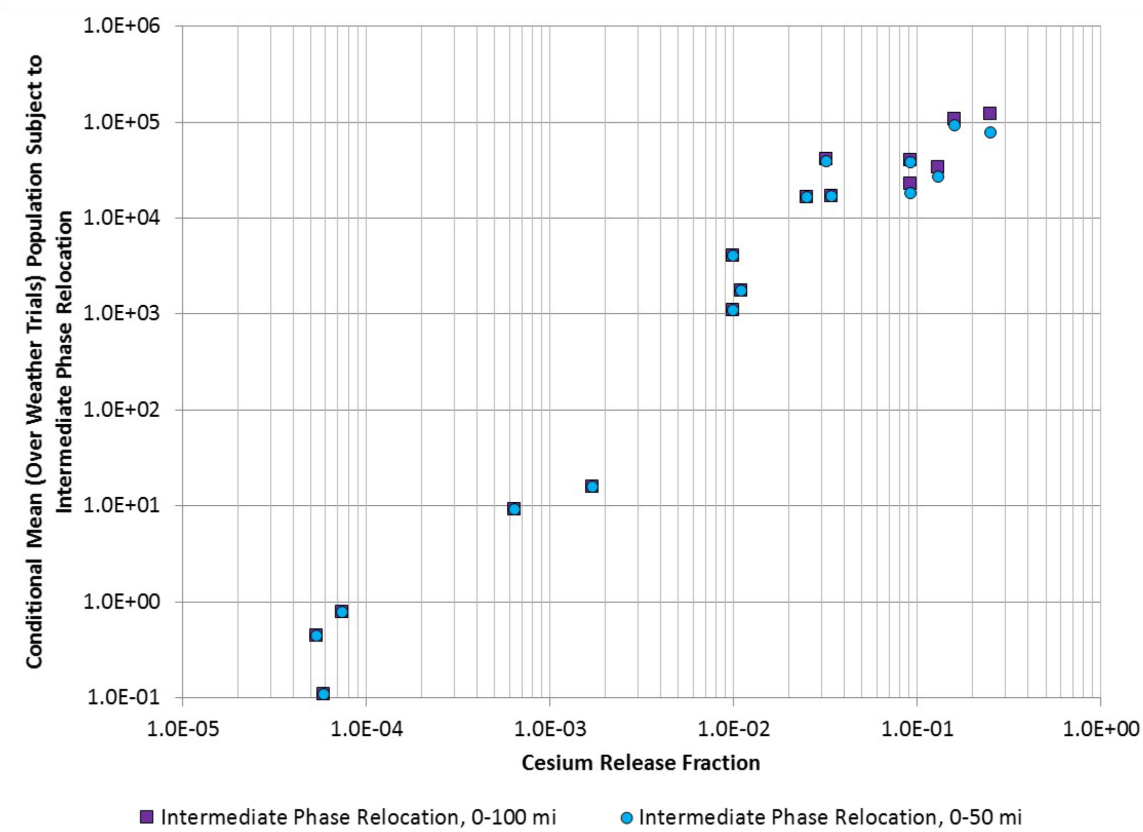


Figure 4.5-4: Contribution of release categories to intermediate-phase affected population size within 100 miles

The mean size of population within 50 and 100 miles subject to intermediate-phase relocation as a function of cesium release fraction, used as a surrogate for the size of the release,[47] is shown in Figure 4.5-5. Two observations may be drawn from this plot:

- The mean size of the population subject to intermediate-phase relocation is closely related to the magnitude of the cesium release fraction across a wide range of release magnitudes.
- The two plots are very similar, suggesting that intermediate-phase relocation is unlikely (on average) to extend beyond 50 miles. There is a very slight difference between the 50 and 100 mile results for the largest releases, suggesting that larger releases may result in a higher likelihood of intermediate-phase relocation beyond 50 miles, but the majority of the affected population is concentrated within 50 miles.



[47] The use of the cesium release fraction as a surrogate for the total magnitude of the release is an approximation because different sequences will release isotopes in different ratios. In addition, different results may be sensitive to different isotopes. However, inspection of the ratio between the total cesium release fraction and the total iodine release fraction suggests that release magnitudes are fairly well correlated across a wide range of release magnitudes, such that the use of cesium release fractions is considered a reasonable surrogate for release magnitude.

Figure 4.5-5: Mean (Across All Weather Trials) size of population subject to intermediate-phase relocation within 50 and 100 miles as a function of cesium release fraction

The relative contribution of different weather bins and release categories to the mean size of the population within 100 miles subject to intermediate-phase relocation is shown in Figure 4.5-6. The stacked bar on the left shows the relative contribution to the mean for a particular weather bin from each release category. The solid blue bar to the right shows the relative frequency of the weather bin. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. These figures suggest that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value. This suggests that this result may not be particularly sensitive to the selection of alternate weather years, because there do not appear to be weather conditions that contribute disproportionately to the mean value. The contributions of individual release categories shown in Figure 4.5-6, dominated by the contributions from the ICF-BURN, LCF, and ISGTR release categories, are consistent with Figure 4.5-4.

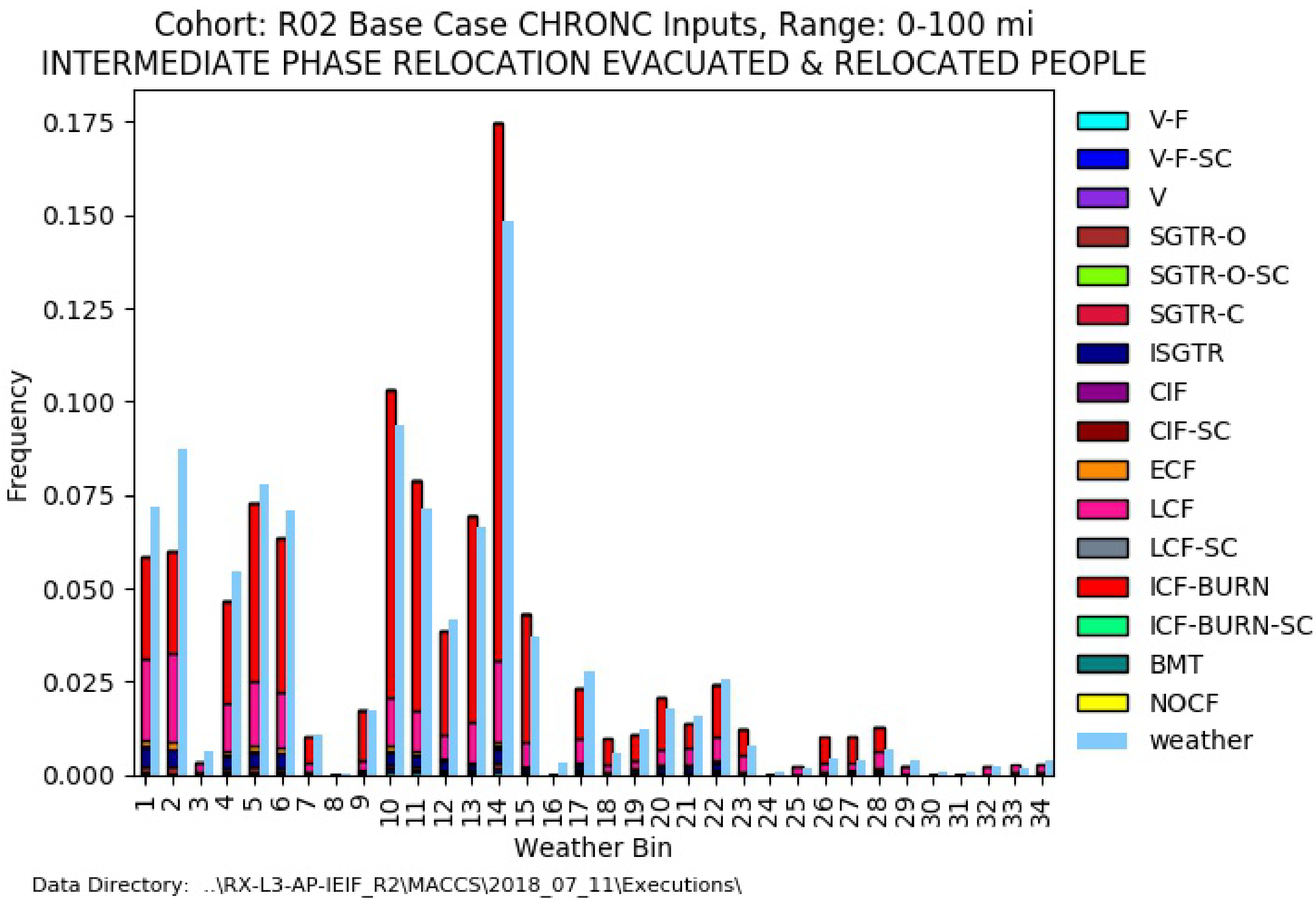


Figure 4.5-6: Relative contribution of release categories and weather bins to frequency-weighted mean (across all weather trials) population subject to intermediate-phase relocation

The complementary cumulative distribution function of the population within 50 and 100 miles subject to intermediate-phase relocation is shown in Figures 4.5-7 and 4.5-8, respectively. The results shown here are consistent with the results seen in Figures 4.5-3 and 4.5-4; namely, that the risk of intermediate-phase population relocation is largely driven by the LCF and ICF-BURN release categories. The ICF-BURN release category appears more likely to result in larger affected population sizes, as seen by the fact that the LCF and ICF-BURN curves cross. This is very similar to the relative contribution of release categories to other aggregate impacts (such as total latent cancer fatality cases or individual latent cancer fatality risk), as well as to the contributions to the mean cesium release fraction and mean iodine release fraction.

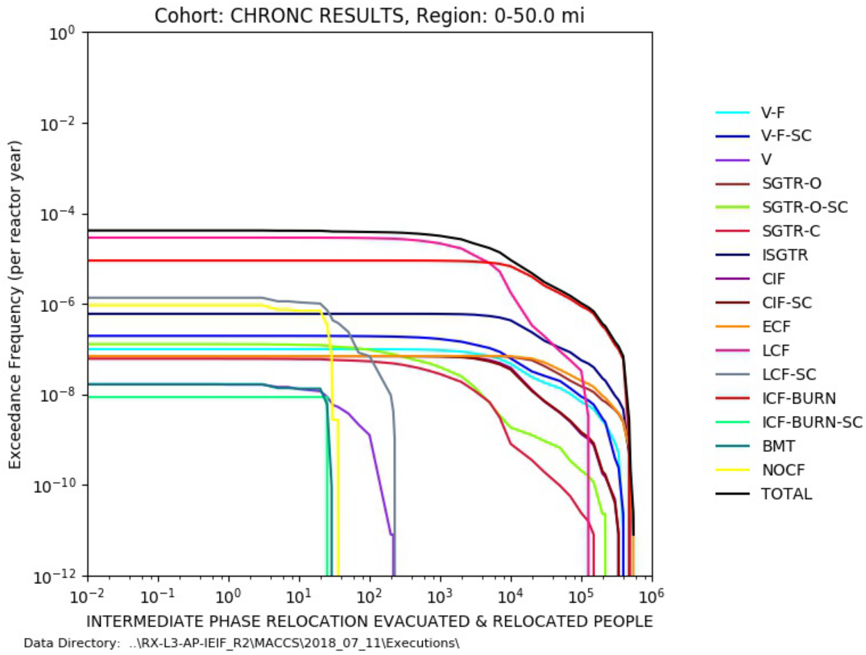


Figure 4.5-7: Complementary cumulative distribution function of population subject to intermediate-phase relocation within 50 miles

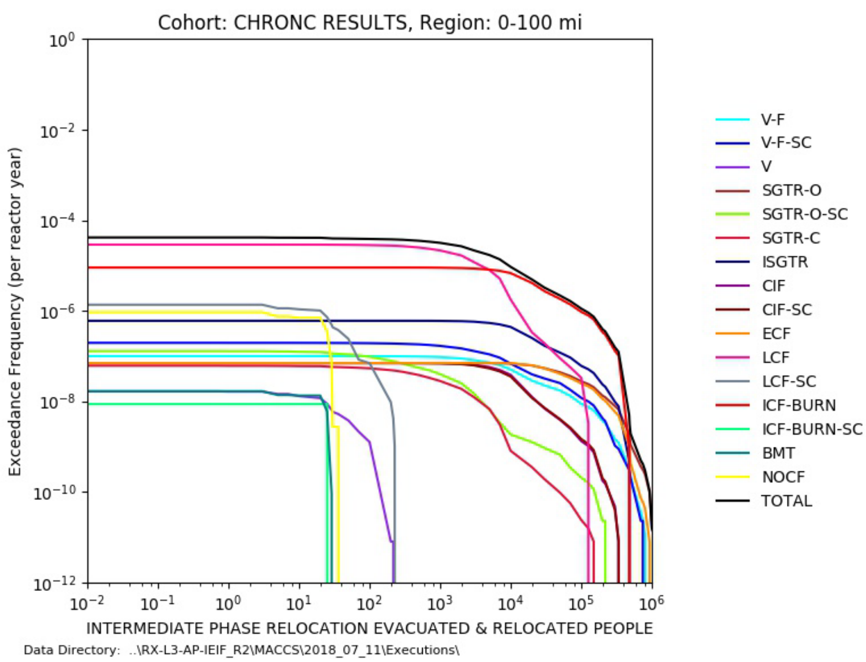


Figure 4.5-8: Complementary cumulative distribution function of population subject to intermediate-phase relocation within 100 miles

4.5.1 Sensitivity Cases

4.5.1.1 *Meteorological Sampling*

The effect of sampling only a subset of the meteorological data on the population relocated during the intermediate phase within 50 and 100 miles is demonstrated in Table 4.5-5 and Table 4.5-6. It is evident from inspection of these results that differences resulting from sampling a representative subset of weather trials as opposed to sampling all 8760 hourly observations are generally less than a few percent. The release categories which showed a larger relative difference (ICF-BURN-SC, BMT, and NOCF) were all characterized by very low base case results (with mean values less than a single person). For these changes, a slight absolute difference in the results can be expected to result in a larger relative difference, due to the low values in the denominator of the ratio.

Table 4.5-5: Summary of population relocated during intermediate phase, 0–50 mi (persons) (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.1E-01**	**5.1E-01**	**1.015**
V-F	1.0E-07	2.7E+04	2.7E+04	1.004
V-F-SC	2.0E-07	1.8E+04	1.9E+04	1.055
V	7.0E-08	9.1E+00	9.0E+00	0.986
SGTR-O	7.0E-08	7.8E+04	7.8E+04	0.997
SGTR-O-SC	2.0E-07	1.1E+03	1.1E+03	1.009
SGTR-C	7.0E-08	1.8E+03	1.8E+03	1.029
ISGTR	6.0E-07	3.7E+04	3.8E+04	1.005
CIF	7.0E-08	1.7E+04	1.7E+04	1.000
CIF-SC	7.0E-08	1.6E+04	1.6E+04	1.000
ECF	7.0E-08	9.3E+04	9.8E+04	1.062
LCF	2.9E-05	4.0E+03	3.7E+03	0.935
LCF-SC	3.0E-06	1.6E+01	1.6E+01	1.032
ICF-BURN	9.0E-06	3.9E+04	4.0E+04	1.042
ICF-BURN-SC	2.0E-06	1.1E-01	2.4E-01	2.241
BMT	8.0E-07	4.4E-01	3.6E-01	0.820
NOCF	2.4E-05	7.8E-01	5.8E-01	0.738

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.5-6: Summary of population relocated during intermediate phase, 0–100 mi (persons) (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.3E-01**	**5.4E-01**	**1.017**
V-F	1.0E-07	3.3E+04	3.2E+04	0.961
V-F-SC	2.0E-07	2.3E+04	2.3E+04	1.035
V	7.0E-08	9.1E+00	9.0E+00	0.986
SGTR-O	7.0E-08	1.2E+05	1.2E+05	1.017
SGTR-O-SC	2.0E-07	1.1E+03	1.1E+03	1.009
SGTR-C	7.0E-08	1.8E+03	1.8E+03	1.029
ISGTR	6.0E-07	4.0E+04	4.0E+04	0.997
CIF	7.0E-08	1.7E+04	1.7E+04	1.006
CIF-SC	7.0E-08	1.6E+04	1.6E+04	1.006
ECF	7.0E-08	1.1E+05	1.1E+05	1.056
LCF	2.9E-05	4.0E+03	3.7E+03	0.935
LCF-SC	3.0E-06	1.6E+01	1.6E+01	1.032
ICF-BURN	9.0E-06	4.0E+04	4.2E+04	1.045
ICF-BURN-SC	2.0E-06	1.1E-01	2.4E-01	2.241
BMT	8.0E-07	4.4E-01	3.6E-01	0.820
NOCF	2.4E-05	7.8E-01	5.8E-01	0.738

1. Results are a frequency-weighted sum of all release categories

2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.5.1.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on the population relocated during the intermediate phase within 50 and 100 miles is demonstrated in Tables 4.5-7 and 4.5-8. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

The effect of terminating the release is a reduction in the population relocated during the intermediate phase. On a frequency-weighted basis, the reduction is approximately a factor of eight. It can be seen that some release categories (such as ISLOCA or SGTR release categories) are relatively unaffected with a reduction on the order of a few percent, whereas other release categories (such as the late containment failure (LCF) release category) are completely eliminated, because the reduced releases were not projected to require an intermediate phase. There is also a significant (>90%) reduction in the intermediate phase relocated population for the ICF-BURN release category.

It may be noted that, as seen in Table 4.5-3 and Table 4.5-4, both of these release categories exhibited an intermediate phase relocated population that was large relative to the combined late phase relocated populations, suggesting that large areas of land were contaminated to levels that would exceed a projected dose of two rem in the year of the accident but that one year of decay and weathering during the intermediate phase was sufficient to reduce large areas to doses less than 500 mrem in the year following the accident; i.e., the first year relocation criteria was more restrictive than the second year criteria for these release categories. If accident releases are terminated 36 hours after SAMG entry, the size of the population relocated during the intermediate phase is generally slightly (approximately 30%) less than the population relocated during the long-term phase, suggesting that the second year criteria is slightly more restrictive.

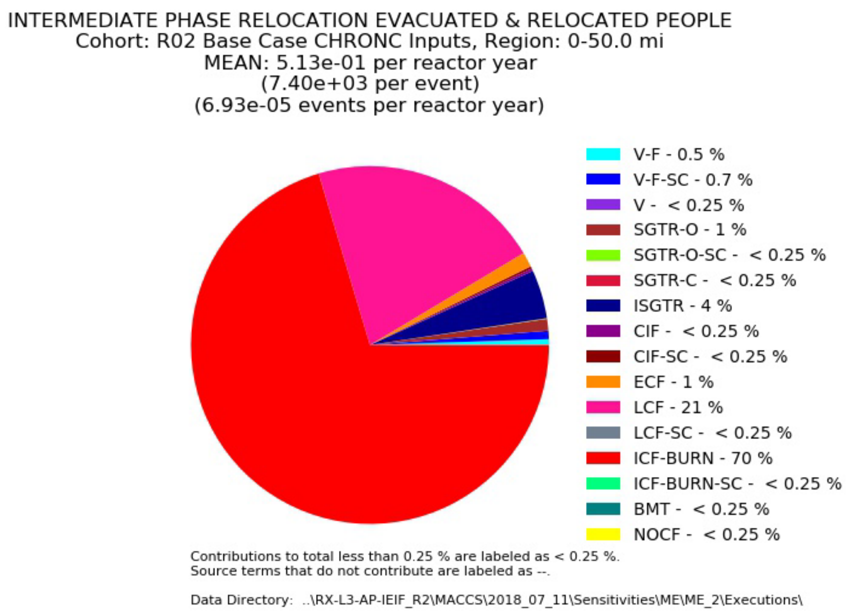
The differential impact of the accident termination time on the relative contribution of release categories to the population relocated during the intermediate phase within 50 and 100 miles is illustrated in Figures 4.5-9 and 4.5-10, respectively. The frequency-weighted reduction in the affected population due to terminating the release is a combination of the elimination of the LCF release category as a contributor coupled with a much lower conditional consequence for the ICF-BURN release category. The relative contribution of release categories to the mean affected population size is similar to the relative contribution of release categories to the cumulative cesium release shown in Figure 5-1, with the ICF-BURN and ISGTR release categories increasing in relative importance and the LCF release category comprising a much smaller contributor. However, due to the large reduction in the intermediate phase affected population for the ICF-BURN release category, the ISGTR release category exhibits a pronounced contribution.

Table 4.5-7: Summary of population relocated during intermediate phase, 0–50 mi (persons) (mean value across all weather trials): RE_4

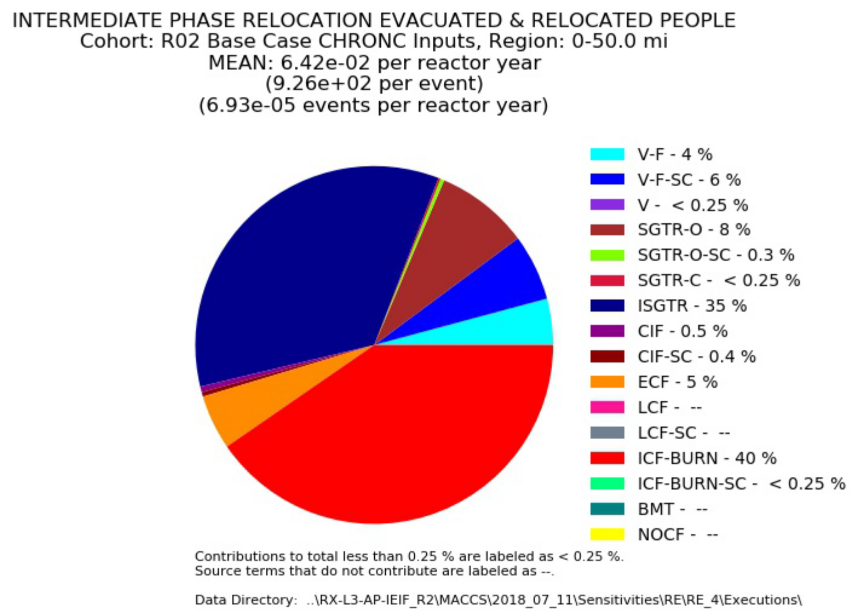
Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.1E-01**	**6.4E-02**	**0.125**
V-F	1.0E-07	2.7E+04	2.7E+04	0.996
V-F-SC	2.0E-07	1.9E+04	1.9E+04	1.000
V	7.0E-08	9.0E+00	8.8E+00	0.978
SGTR-O	7.0E-08	7.8E+04	7.8E+04	0.997
SGTR-O-SC	2.0E-07	1.1E+03	1.1E+03	1.000
SGTR-C	7.0E-08	1.8E+03	1.8E+03	0.994
ISGTR	6.0E-07	3.8E+04	3.7E+04	0.984
CIF	7.0E-08	1.7E+04	4.7E+03	0.282
CIF-SC	7.0E-08	1.6E+04	3.7E+03	0.229
ECF	7.0E-08	9.8E+04	4.5E+04	0.462
LCF	2.9E-05	3.7E+03	-	-
LCF-SC	3.0E-06	1.6E+01	-	-
ICF-BURN	9.0E-06	4.0E+04	2.9E+03	0.072
ICF-BURN-SC	2.0E-06	2.4E-01	2.4E-01	1.000
BMT	8.0E-07	3.6E-01	-	-
NOCF	2.4E-05	5.8E-01	-	-

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



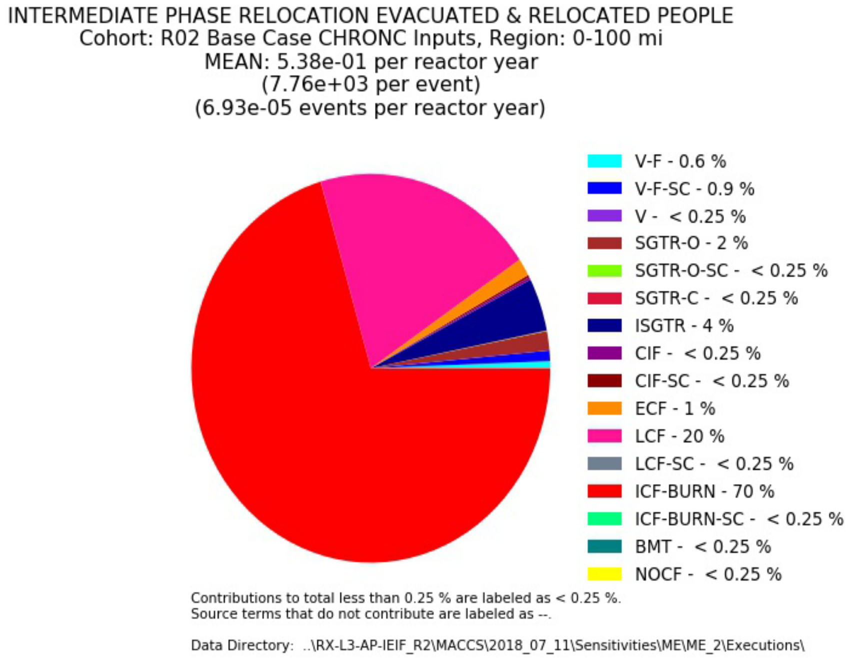
RE_4

Figure 4.5-9: Relative contribution of release categories to population relocated during intermediate phase, 0–50 mi (persons): RE_4

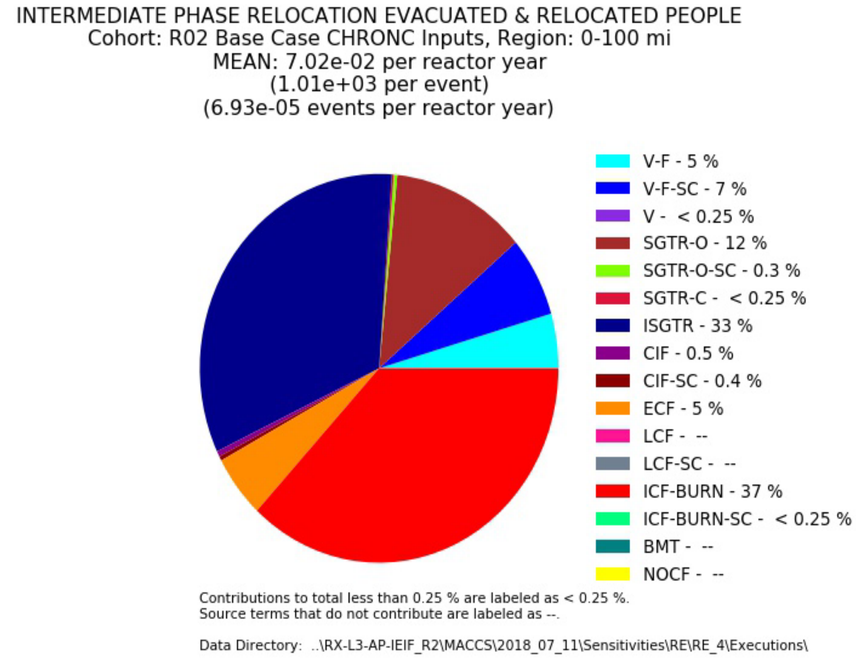
Table 4.5-8: Summary of population relocated during intermediate phase, 0–100 mi (persons) (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**5.4E-01**	**7.0E-02**	**0.131**
V-F	1.0E-07	3.2E+04	3.2E+04	0.997
V-F-SC	2.0E-07	2.3E+04	2.3E+04	1.000
V	7.0E-08	9.0E+00	8.8E+00	0.978
SGTR-O	7.0E-08	1.2E+05	1.2E+05	0.992
SGTR-O-SC	2.0E-07	1.1E+03	1.1E+03	1.000
SGTR-C	7.0E-08	1.8E+03	1.8E+03	0.994
ISGTR	6.0E-07	4.0E+04	3.9E+04	0.982
CIF	7.0E-08	1.7E+04	4.7E+03	0.280
CIF-SC	7.0E-08	1.6E+04	3.7E+03	0.228
ECF	7.0E-08	1.1E+05	5.2E+04	0.462
LCF	2.9E-05	3.7E+03	-	-
LCF-SC	3.0E-06	1.6E+01	-	-
ICF-BURN	9.0E-06	4.2E+04	2.9E+03	0.068
ICF-BURN-SC	2.0E-06	2.4E-01	2.4E-01	1.000
BMT	8.0E-07	3.6E-01	-	-
NOCF	2.4E-05	5.8E-01	-	-

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



RE_4

Figure 4.5-10: Relative contribution of release categories to population relocated during intermediate phase, 0–100 mi (persons): RE_4

4.5.1.3 *Low-Dose Cancer Risk Estimation*

Inspection of the results for the estimated size of populations subject to intermediate phase relocation results arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem), shows that (as expected) there is no significant difference between the results of the reference case and the results for sensitivity case HE-2. For this sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of using a dose truncation model. The ratio of the results of the reference and sensitivity case were 1.000 for all release categories and are therefore not reproduced here.[48]

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[48] Although the ratio of HE_2 intermediate and recovery phase relocated populations to ME_2 intermediate and recovery phase relocated populations was 1.000 for all release categories, slight (≤10% for all but the smallest values) differences were observed for early phase affected populations (evacuees affected and unaffected by the plume as well as hot-spot and normal relocated populations). The reason for these reductions is unclear.

4.6 Economic Costs

Economic costs arise from the protective actions assumed to be taken to reduce exposures arising from the accident. They include the daily costs for evacuees and relocatees, as well as the cost associated with the depreciation and loss of use of interdicted property, the cost of decontamination or condemnation, and the costs arising from the implementation of agricultural countermeasures. The economic costs are characterized in terms of the total cost of protective actions within 50 and 100 miles of the site. The MACCS Type 10 output is used to tabulate economic costs.

The mean costs associated with agricultural restrictions within 50 and 100 miles are shown in Table 4.6-1 and Table 4.6-2, respectively. The mean costs associated with population restrictions within 50 and 100 miles are shown in Table 4.6-3 and Table 4.6-4, respectively.

Table 4.6-1: Mean (across all weather trials) economic costs within 50 miles for agricultural restrictions (2015$)

Release Category	Frequency (/rcy)	Crop Disposal	Milk Disposal	Farmland Decontamination	Farmland Interdiction	Farmland Condemnation	Total Farm-Dependent
V-F	1.0E-07	1.2E+08	2.0E+06	0.0E+00	9.2E+07	2.1E+08	4.2E+08
V-F-SC	2.0E-07	9.6E+07	1.7E+06	0.0E+00	7.7E+07	1.4E+08	3.1E+08
V	7.0E-08	1.6E+07	7.1E+05	0.0E+00	1.4E+07	3.4E+06	3.4E+07
SGTR-O	7.0E-08	2.2E+08	4.2E+06	0.0E+00	1.4E+08	6.0E+08	9.6E+08
SGTR-O-SC	2.0E-07	5.0E+07	1.0E+06	0.0E+00	4.4E+07	1.8E+07	1.1E+08
SGTR-C	7.0E-08	7.3E+07	2.3E+06	0.0E+00	6.8E+07	3.9E+07	1.8E+08
ISGTR	6.0E-07	3.0E+08	5.6E+06	0.0E+00	2.4E+08	3.4E+08	8.7E+08
CIF	7.0E-08	2.4E+08	4.9E+06	0.0E+00	2.2E+08	1.1E+08	5.8E+08
CIF-SC	7.0E-08	1.8E+08	4.3E+06	0.0E+00	1.6E+08	7.8E+07	4.2E+08
ECF	7.0E-08	2.9E+08	5.1E+06	0.0E+00	2.3E+08	4.3E+08	9.5E+08
LCF	2.9E-05	1.5E+08	3.8E+06	0.0E+00	1.3E+08	2.4E+07	3.1E+08
LCF-SC	3.0E-06	2.3E+07	8.5E+05	0.0E+00	2.2E+07	7.0E+06	5.2E+07
ICF-BURN	9.0E-06	2.2E+08	4.3E+06	0.0E+00	1.9E+08	8.1E+07	5.0E+08
ICF-BURN-SC	2.0E-06	1.2E+06	1.3E+05	0.0E+00	1.3E+06	2.5E+05	2.9E+06
BMT	8.0E-07	8.1E+05	1.1E+05	0.0E+00	9.5E+05	8.0E+04	1.9E+06
NOCF	2.4E-05	1.4E+06	1.6E+05	0.0E+00	1.6E+06	3.4E+05	3.5E+06

Table 4.6-2: Mean (Across All Weather Trials) economic costs within 100 miles for agricultural restrictions (2015$)

Release Category	Frequency (/rcy)	Crop Disposal	Milk Disposal	Farmland Decontamination	Farmland Interdiction	Farmland Condemnation	Total Farm-Dependent
V-F	1.0E-07	4.3E+08	7.2E+06	0.0E+00	3.6E+08	2.7E+08	1.1E+09
V-F-SC	2.0E-07	3.6E+08	6.1E+06	0.0E+00	3.0E+08	1.8E+08	8.4E+08
V	7.0E-08	1.9E+07	1.4E+06	0.0E+00	1.6E+07	3.4E+06	3.9E+07
SGTR-O	7.0E-08	7.4E+08	1.3E+07	0.0E+00	5.5E+08	1.0E+09	2.3E+09
SGTR-O-SC	2.0E-07	1.5E+08	3.0E+06	0.0E+00	1.1E+08	1.8E+07	2.8E+08
SGTR-C	7.0E-08	2.0E+08	5.0E+06	0.0E+00	1.7E+08	3.9E+07	4.2E+08
ISGTR	6.0E-07	9.0E+08	1.8E+07	0.0E+00	7.1E+08	3.8E+08	2.0E+09
CIF	7.0E-08	6.1E+08	1.4E+07	0.0E+00	4.9E+08	1.1E+08	1.2E+09
CIF-SC	7.0E-08	4.2E+08	1.1E+07	0.0E+00	3.4E+08	7.9E+07	8.5E+08
ECF	7.0E-08	9.1E+08	1.6E+07	0.0E+00	7.3E+08	5.5E+08	2.2E+09
LCF	2.9E-05	2.6E+08	9.1E+06	0.0E+00	2.0E+08	2.4E+07	5.0E+08
LCF-SC	3.0E-06	2.4E+07	9.1E+05	0.0E+00	2.3E+07	7.0E+06	5.5E+07
ICF-BURN	9.0E-06	6.0E+08	1.2E+07	0.0E+00	4.6E+08	8.1E+07	1.2E+09
ICF-BURN-SC	2.0E-06	1.2E+06	1.3E+05	0.0E+00	1.3E+06	2.5E+05	2.9E+06
BMT	8.0E-07	8.1E+05	1.1E+05	0.0E+00	9.5E+05	8.0E+04	1.9E+06
NOCF	2.4E-05	1.4E+06	1.6E+05	0.0E+00	1.6E+06	3.4E+05	3.5E+06

Table 4.6-3: Mean (across all weather trials) economic costs within 50 miles for population restrictions (2015$)

Release Category	Frequency (/rcy)	Emergency Phase	Intermediate Phase	Population-Dependent Decontamination	Population-Dependent Interdiction	Population-Dependent Condemnation	Total Population-Dependent
V-F	1.0E-07	2.0E+08	1.3E+09	4.4E+08	3.6E+09	1.1E+07	5.5E+09
V-F-SC	2.0E-07	1.9E+08	8.6E+08	3.0E+08	2.6E+09	6.1E+06	3.9E+09
V	7.0E-08	2.5E+07	1.1E+05	3.5E+05	2.8E+06	0.0E+00	2.9E+07
SGTR-O	7.0E-08	2.5E+08	3.7E+09	1.6E+09	9.4E+09	9.8E+07	1.5E+10
SGTR-O-SC	2.0E-07	5.1E+07	5.1E+07	1.7E+07	1.8E+08	1.0E+04	2.9E+08
SGTR-C	7.0E-08	1.2E+08	8.3E+07	3.1E+07	3.1E+08	3.8E+05	5.5E+08
ISGTR	6.0E-07	2.3E+08	1.8E+09	5.5E+08	5.0E+09	1.0E+07	7.5E+09
CIF	7.0E-08	1.3E+08	7.9E+08	7.4E+07	1.4E+09	6.0E+05	2.4E+09
CIF-SC	7.0E-08	1.3E+08	7.7E+08	5.6E+07	1.3E+09	5.1E+05	2.3E+09
ECF	7.0E-08	1.8E+08	4.4E+09	7.9E+08	9.0E+09	1.8E+07	1.4E+10
LCF	2.9E-05	5.9E+07	1.9E+08	2.5E+06	2.6E+08	0.0E+00	5.1E+08
LCF-SC	3.0E-06	2.8E+07	1.9E+05	4.4E+05	3.8E+06	0.0E+00	3.3E+07
ICF-BURN	9.0E-06	1.3E+08	1.8E+09	4.7E+07	2.6E+09	1.9E+05	4.6E+09
ICF-BURN-SC	2.0E-06	6.2E+06	1.3E+03	6.3E+03	5.9E+04	0.0E+00	6.3E+06
BMT	8.0E-07	3.1E+07	5.2E+03	1.1E+03	1.8E+04	0.0E+00	3.1E+07
NOCF	2.4E-05	3.1E+07	9.3E+03	9.1E+03	9.4E+04	0.0E+00	3.1E+07

Table 4.6-4: Mean (across all weather trials) economic costs within 100 miles for population restrictions (2015$)

Release Category	Frequency (/rcy)	Emergency Phase	Intermediate Phase	Population-Dependent Decontamination	Population-Dependent Interdiction	Population-Dependent Condemnation	Total Population-Dependent
V-F	1.0E-07	2.3E+08	1.6E+09	5.3E+08	4.7E+09	1.1E+07	7.0E+09
V-F-SC	2.0E-07	2.1E+08	1.1E+09	3.6E+08	3.3E+09	6.1E+06	4.9E+09
V	7.0E-08	2.5E+07	1.1E+05	3.5E+05	2.8E+06	0.0E+00	2.9E+07
SGTR-O	7.0E-08	2.8E+08	5.7E+09	2.2E+09	1.7E+10	9.8E+07	2.6E+10
SGTR-O-SC	2.0E-07	5.1E+07	5.1E+07	1.7E+07	1.8E+08	1.0E+04	2.9E+08
SGTR-C	7.0E-08	1.2E+08	8.3E+07	3.1E+07	3.1E+08	3.8E+05	5.5E+08
ISGTR	6.0E-07	2.3E+08	1.9E+09	6.1E+08	5.7E+09	1.0E+07	8.4E+09
CIF	7.0E-08	1.3E+08	7.9E+08	7.4E+07	1.5E+09	6.0E+05	2.4E+09
CIF-SC	7.0E-08	1.3E+08	7.7E+08	5.6E+07	1.3E+09	5.1E+05	2.3E+09
ECF	7.0E-08	1.8E+08	5.1E+09	9.6E+08	1.2E+10	1.8E+07	1.8E+10
LCF	2.9E-05	5.9E+07	1.9E+08	2.5E+06	2.6E+08	0.0E+00	5.1E+08
LCF-SC	3.0E-06	2.8E+07	1.9E+05	4.4E+05	3.8E+06	0.0E+00	3.3E+07
ICF-BURN	9.0E-06	1.3E+08	1.9E+09	4.7E+07	2.7E+09	1.9E+05	4.8E+09
ICF-BURN-SC	2.0E-06	6.2E+06	1.3E+03	6.3E+03	5.9E+04	0.0E+00	6.3E+06
BMT	8.0E-07	3.1E+07	5.2E+03	1.1E+03	1.8E+04	0.0E+00	3.1E+07
NOCF	2.4E-05	3.1E+07	9.3E+03	9.1E+03	9.4E+04	0.0E+00	3.1E+07

The release-category-frequency-weighted relative contribution of different protective actions in the early, intermediate, and late (recovery) phases within 50 and 100 miles is shown in Figures 4.6-1 and 4.6-2, respectively. Population-dependent costs appear to be the largest contributor to costs. Figures 4.6-1 and 4.6-2 suggest that interdiction of property in the intermediate- and long-term phases, as well as daily costs from relocation of large numbers of persons in the intermediate phase, may result in significant costs. In addition, crop disposal (in the year of the accident) and interdiction of farmland (to allow weathering and decay to reduce levels of contamination) may also result in significant costs. Comparison of Figures 4.6-1 and 4.6-2 suggest that at distances greater than 50 miles, agricultural costs may represent an increasing share of total impacts.

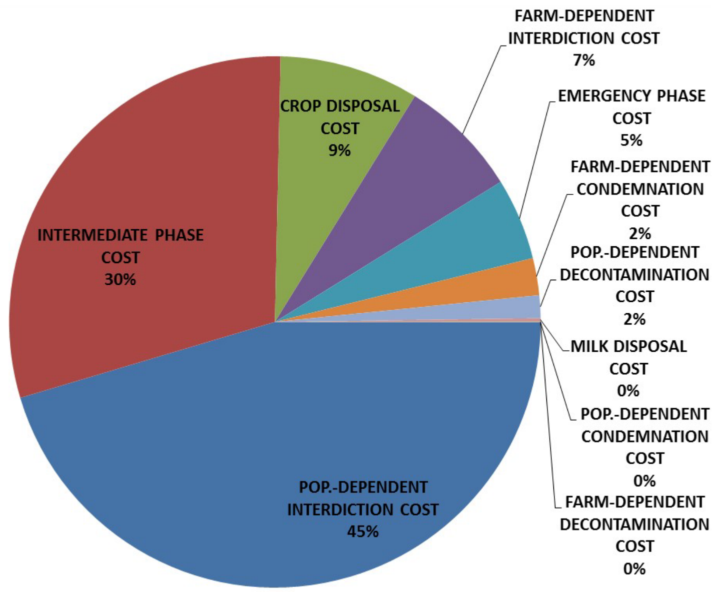


Figure 4.6-1: Relative contribution of protective actions to total frequency-weighted economic costs within 50 miles

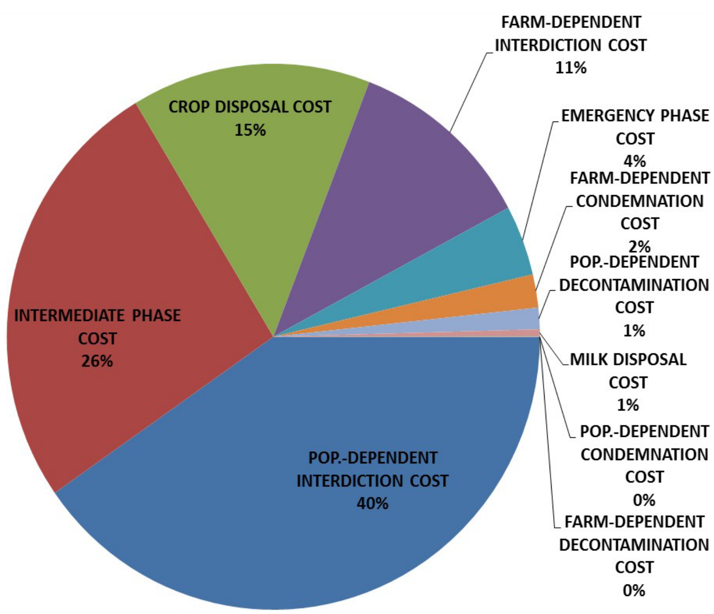


Figure 4.6-2: Relative contribution of protective actions to total frequency-weighted economic costs within 100 miles

The relative contribution of different release categories to the total frequency-weighted costs within 50 and 100 miles are shown in Figures 4.6-3 and 4.6-4, respectively. These figures suggest that, similar to many other measures (such as collective dose, total latent cancer fatalities, land contamination, and affected populations), the frequency-weighted economic costs are dominated by the LCF, ICF-BURN, and ISGTR release categories. The similarity of this figure to Figure 3.1-1, showing the relative contribution of release categories to the mean frequency-weighted cesium release fraction, suggests that the magnitude of the cesium release fraction is important in determining the extent of economic costs.

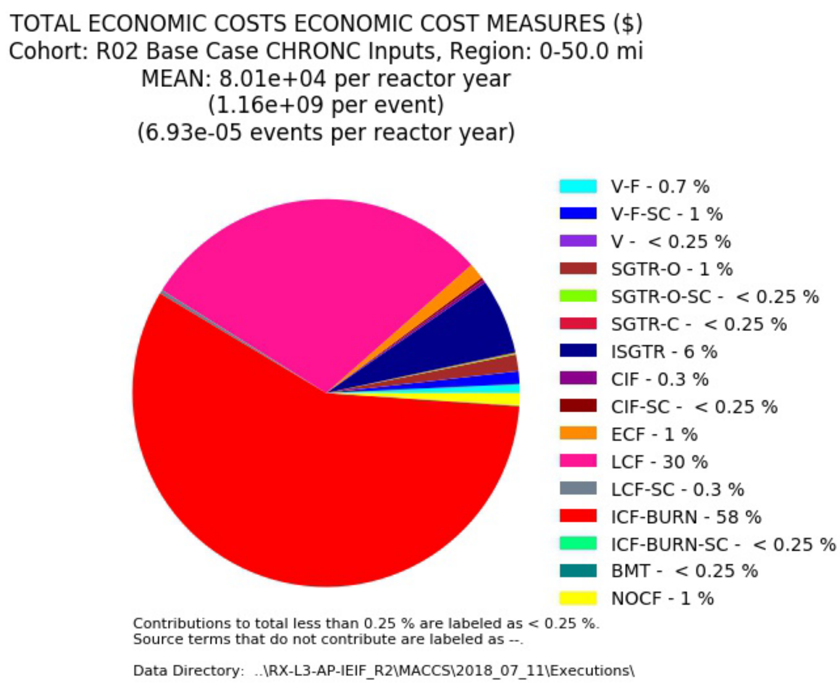


Figure 4.6-3: Relative contribution of release categories to total frequency-weighted economic costs within 50 miles

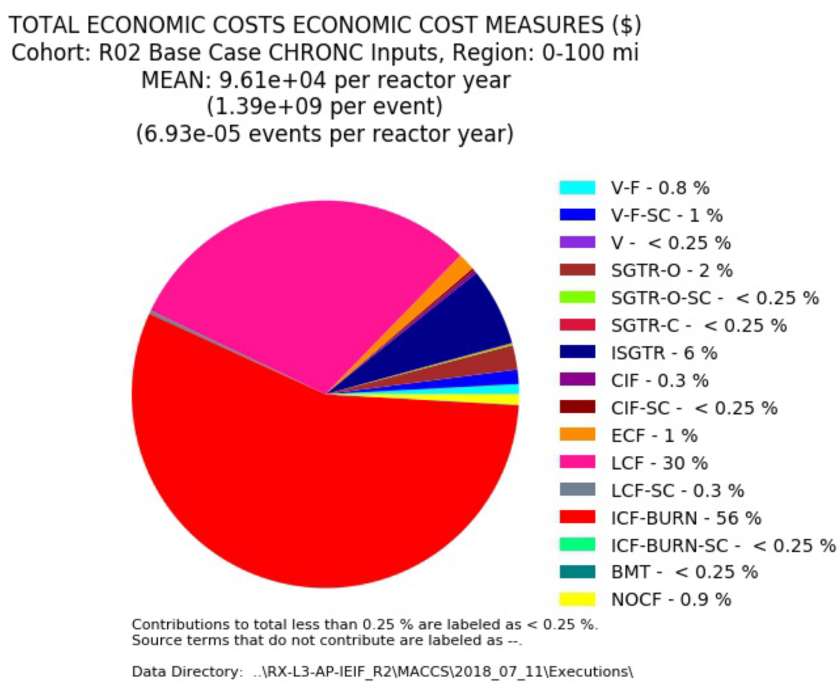


Figure 4.6-4: Relative contribution of release categories to total frequency-weighted economic costs within 100 miles

The mean total economic costs within 50 and 100 miles as a function of cesium release fraction, used as a surrogate for the size of the release,[49] is shown in Figure 4.6-5. This figure suggests that the total economic costs are closely related to the magnitude of the cesium release fraction across a wide range of release magnitudes.

The difference between the 50- and 100-mile economic results can be examined in Figure 4.6-5. Inspection of these figures, as well as the results in the tables, show that for lower release magnitudes, there does not appear to be a significant difference in the 50- and 100-mile costs, suggesting that the majority of the economic impacts are within 50 miles. For higher magnitude releases (greater than approximately 1 percent Cs release fraction), the results begin to diverge, suggesting additional impacts beyond 50 miles. However, even for the largest releases, the differences are less than a factor of 2, suggesting that the majority of the economic impacts will occur within 50 miles for the types of source terms considered here.

[49] The use of the cesium release fraction as a surrogate for the total magnitude of the release is an approximation because different sequences will release isotopes in different ratios. In addition, different results may be sensitive to different isotopes. However, inspection of the ratio between the total cesium release fraction and the total iodine release fraction suggests that release magnitudes are fairly well correlated across a wide range of release magnitudes, such that the use of cesium release fractions is considered a reasonable surrogate for release magnitude.

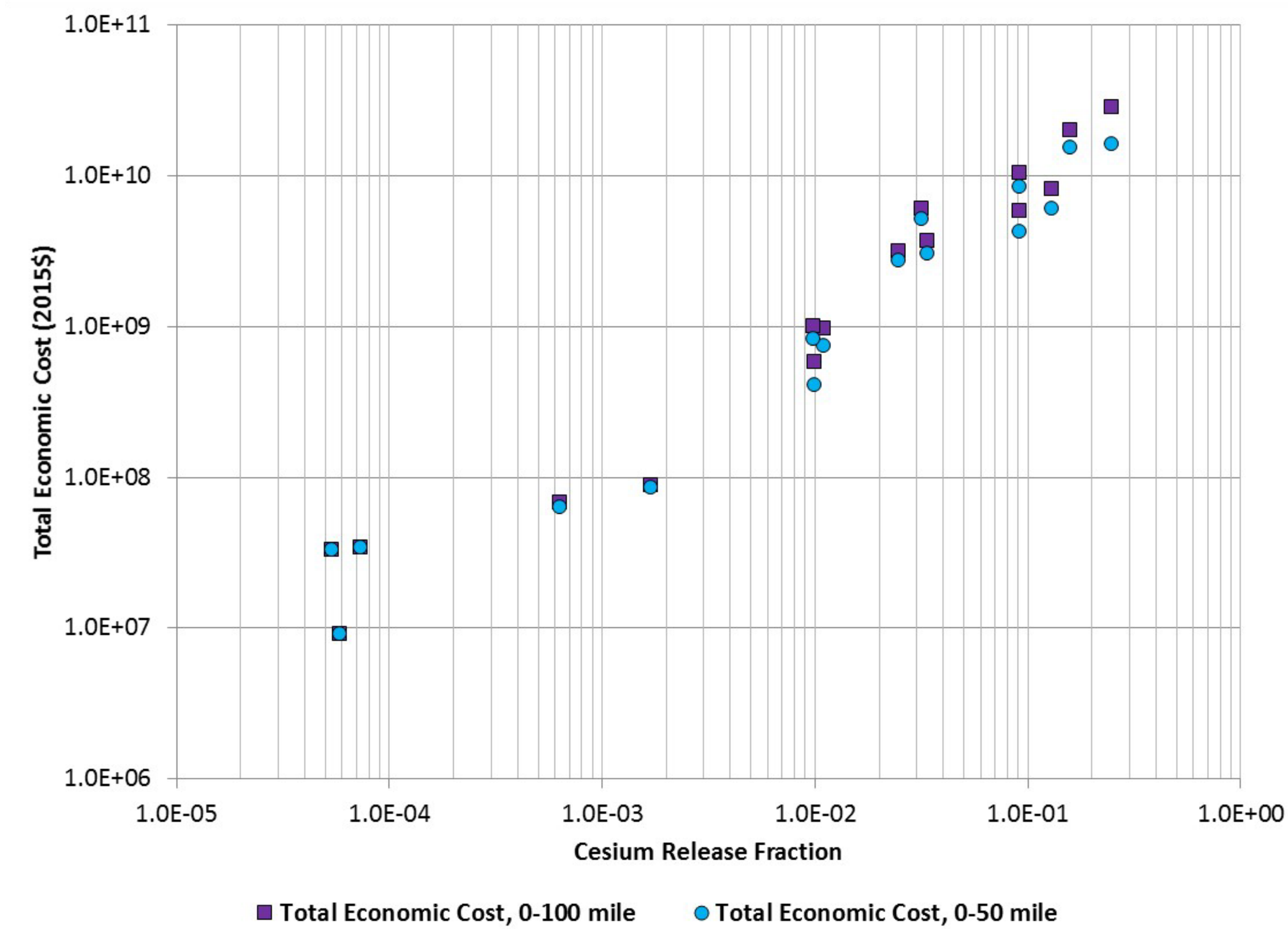


Figure 4.6-5: Mean (across all weather trials) total economic costs (2015$) within 50 and 100 miles as a function of cesium release fraction

The relative contribution of different weather bins and release categories to the mean total economic costs within 50 and 100 miles is shown in Figure 4.6-6a and Figure 4.6-6b, respectively. The stacked bar on the left shows the relative contribution to the mean for a particular weather bin from each release category. The solid blue bar to the right shows the relative frequency of the weather bin. No pronounced difference in the relative contribution of release categories across different weather bins is particularly noticeable. These figures suggest that although some weather conditions may result in conditional consequences above or below the mean value, the effect is not particularly pronounced and the relative frequency of occurrence of different weather conditions is a relatively good predictor of the contribution of that bin to the mean value. This suggests that economic costs may not be particularly sensitive to the selection of alternate weather years, because there do not appear to be weather conditions that contribute disproportionately to the mean value. This could be confirmed by sensitivity analyses using weather files derived from different weather years. The contributions of individual release categories shown in Figure 4.6-6, dominated by the contributions from the ICF-BURN, LCF, and ISGTR release categories, are consistent with Figure 4.6-3 and Figure 4.6-4.

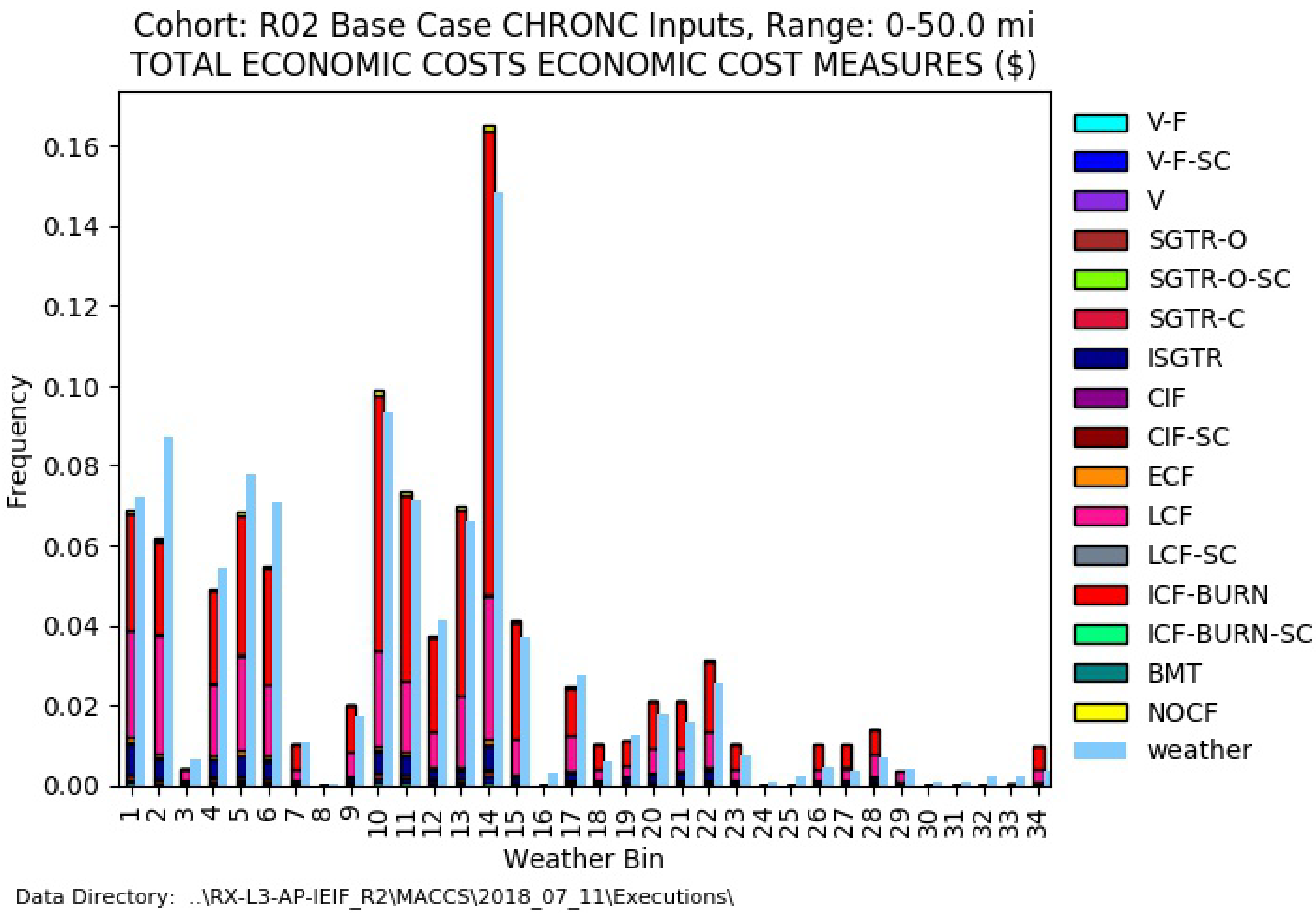


Figure 4.6-6a: Relative contribution of release categories and weather bins to frequency-weighted mean (across all weather trials) total economic costs within 50 miles

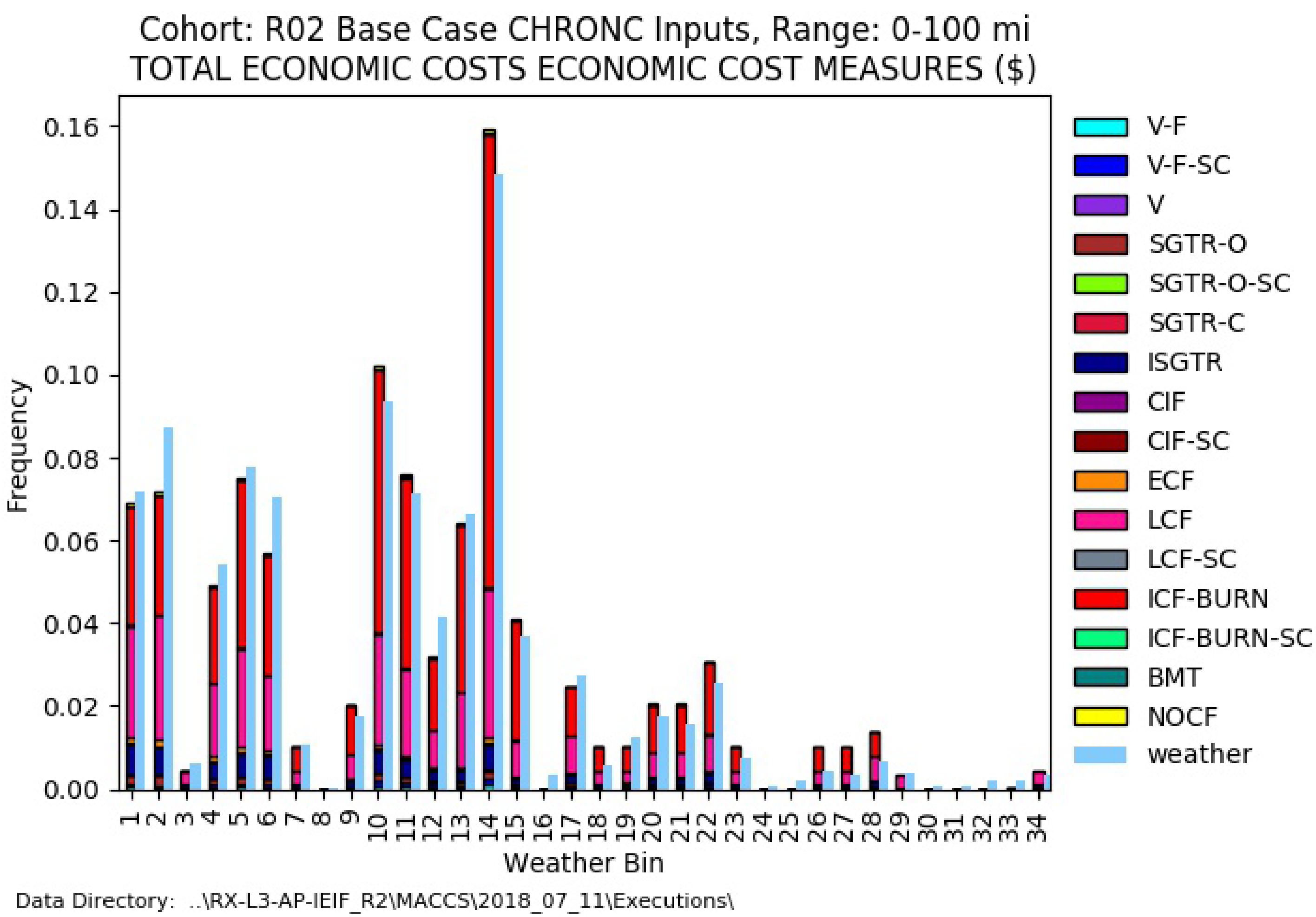


Figure 4.6-6b: Relative contribution of release categories and weather bins to frequency-weighted mean (across all weather trials) total economic costs within 100 miles

The complementary cumulative distribution functions for total economic costs within 50 and 100 miles are shown in Figures 4.6-7 and 4.6-8, respectively. Inspection of Figures 4.6-7 and 4.6-8 shows an interesting feature related to costs; namely, that the costs associated with the NOCF and BMT release categories do not appear to be strongly dependent on meteorological variability. That is, the CCDF curves for these release categories show very little variability, as seen by the relatively rapid dropoff in the frequency of exceeding a value of 50 million 2015$. A possible explanation for this effect is that for these scenarios, which are dominated by early-phase costs, the size of (and therefore the costs associated with) the evacuated population may be relatively independent of weather (i.e., most of the full 10-mile EPZ is evacuated regardless of the meteorological conditions).

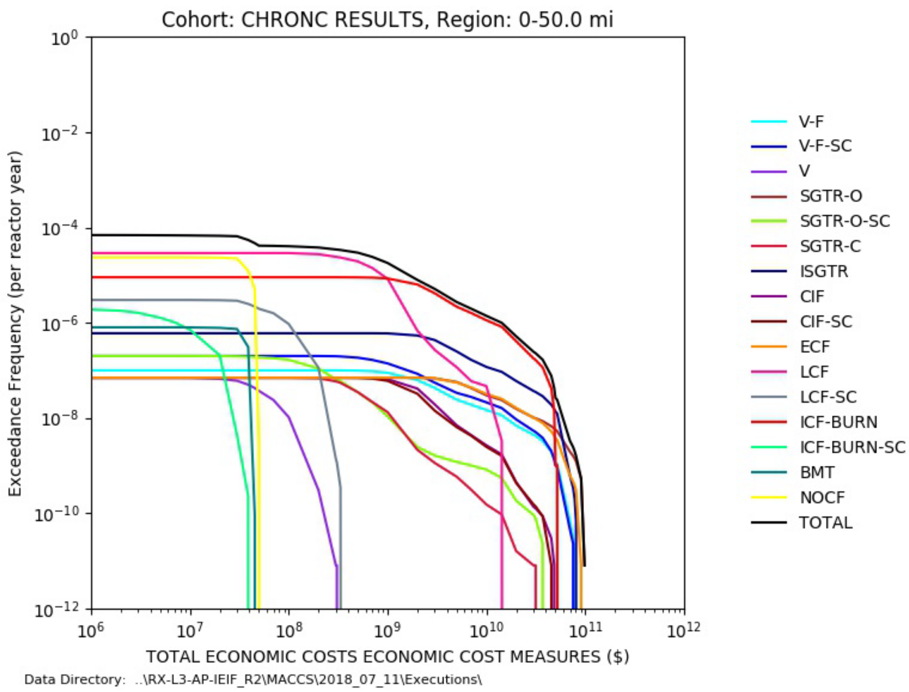


Figure 4.6-7: Complementary cumulative distribution function of total economic costs within 50 miles

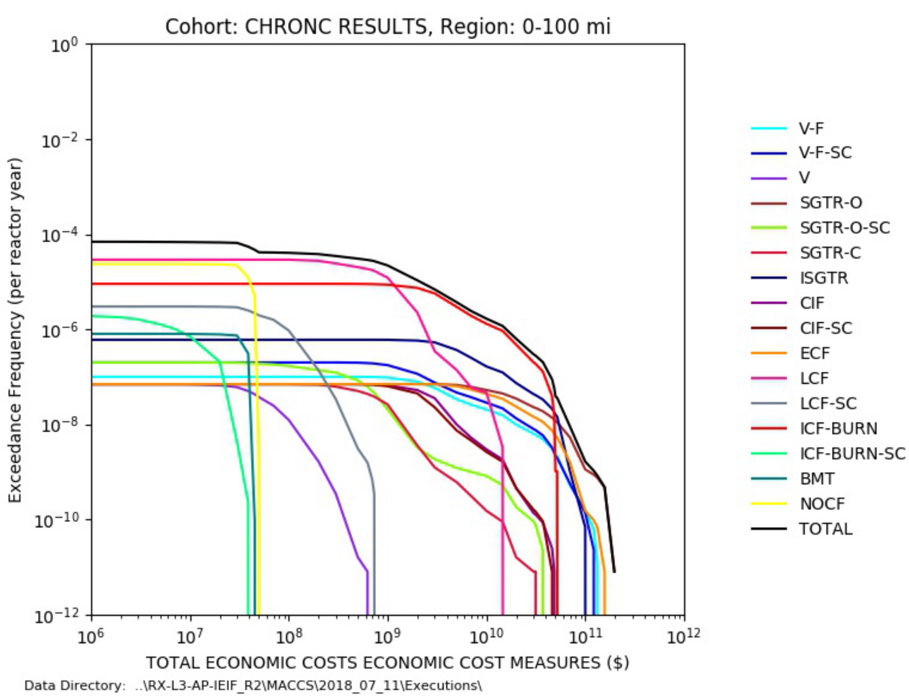


Figure 4.6-8: Complementary cumulative distribution function of total economic costs within 100 miles

4.6.1 Sensitivity Cases

4.6.1.1 *Meteorological Sampling*

The effect of sampling only a subset of the meteorological data on the total economic costs within 50 and 100 miles is demonstrated in Table 4.5-5 and Table 4.5-6. It is evident from inspection of these results that differences resulting from sampling a representative subset of weather trials as opposed to sampling all 8760 hourly observations are generally less than a few percent.

Table 4.6-5: Summary of total economic costs, 0–50 mi (2015$) (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**8.0E+04**	**8.1E+04**	**1.012**
V-F	1.0E-07	6.0E+09	5.9E+09	0.992
V-F-SC	2.0E-07	4.2E+09	4.3E+09	1.026
V	7.0E-08	6.3E+07	6.3E+07	1.005
SGTR-O	7.0E-08	1.6E+10	1.6E+10	1.000
SGTR-O-SC	2.0E-07	4.1E+08	4.3E+08	1.062
SGTR-C	7.0E-08	7.4E+08	7.6E+08	1.031
ISGTR	6.0E-07	8.4E+09	8.4E+09	1.006
CIF	7.0E-08	3.0E+09	3.0E+09	1.007
CIF-SC	7.0E-08	2.7E+09	2.7E+09	1.015
ECF	7.0E-08	1.5E+10	1.6E+10	1.046
LCF	2.9E-05	8.2E+08	7.9E+08	0.968
LCF-SC	3.0E-06	8.5E+07	8.6E+07	1.008
ICF-BURN	9.0E-06	5.1E+09	5.3E+09	1.035
ICF-BURN-SC	2.0E-06	9.1E+06	9.3E+06	1.024
BMT	8.0E-07	3.3E+07	3.3E+07	0.997
NOCF	2.4E-05	3.4E+07	3.4E+07	0.991

1. Results are a frequency-weighted sum of all release categories
2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

Table 4.6-6: Summary of total economic costs, 0–100 mi (2015$) (mean value across all weather trials): ME_2

Release Category	Frequency (/rcy)	Base Case	ME_2	Fraction of Base Case[2]
ALL[1] (per rcy)	**6.9E-05**	**9.6E+04**	**9.8E+04**	**1.017**
V-F	1.0E-07	8.1E+09	7.7E+09	0.953
V-F-SC	2.0E-07	5.8E+09	5.8E+09	1.005
V	7.0E-08	6.8E+07	6.8E+07	0.997
SGTR-O	7.0E-08	2.8E+10	2.8E+10	1.014
SGTR-O-SC	2.0E-07	5.8E+08	6.0E+08	1.047
SGTR-C	7.0E-08	9.7E+08	9.9E+08	1.024
ISGTR	6.0E-07	1.0E+10	1.1E+10	1.010
CIF	7.0E-08	3.7E+09	3.7E+09	1.008
CIF-SC	7.0E-08	3.1E+09	3.7E+09	1.013
ECF	7.0E-08	2.0E+10	2.1E+10	1.035
LCF	2.9E-05	1.0E+09	9.9E+08	0.986
LCF-SC	3.0E-06	8.7E+07	8.8E+07	1.003
ICF-BURN	9.0E-06	6.0E+09	6.2E+09	1.035
ICF-BURN-SC	2.0E-06	9.1E+06	9.3E+06	1.024
BMT	8.0E-07	3.3E+07	3.3E+07	0.997
NOCF	2.4E-05	3.4E+07	3.4E+07	0.991

1. Results are a frequency-weighted sum of all release categories
2. Fraction of base case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded base case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.

4.6.1.2 *Accident Termination Time*

The effect of terminating the accident release 36 hours after SAMG entry on economic costs within 50 and 100 miles is demonstrated in Tables 4.6-7 and 4.6-8. For sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of accident termination time.

The effect of terminating the release is a reduction in the economic costs. On a frequency-weighted basis, the reduction is approximately a factor of four. It can be seen that some release categories (such as ISLOCA or SGTR release categories) are relatively unaffected with a reduction on the order of a few percent, whereas other release categories (such as the late containment failure (LCF) release category) are reduced by almost 99%.

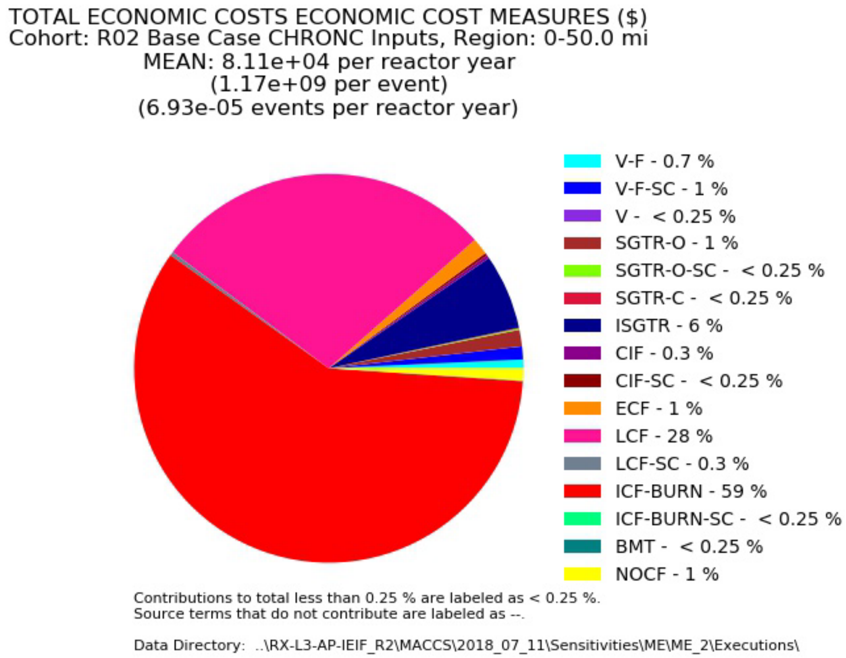
The differential impact of the accident termination time on the relative contribution of release categories to the economic costs within 50 and 100 miles is illustrated in Figures 4.6-9 and 4.6-10, respectively. The frequency weighted reduction in the economic costs due to terminating the release is a combination of the elimination of the LCF release category as a significant contributor coupled with a lower conditional consequence for the ICF-BURN release category. The relative contribution of release categories to the mean total economic costs is similar to the relative contribution of release categories to the cumulative cesium release shown in Figure 5-1, with the ICF-BURN and ISGTR release categories increasing in relative importance and the LCF release category comprising a much smaller contributor.

Table 4.6-7: Summary of total economic costs, 0–50 mi (2015$) (mean value across all weather trials): RE_4

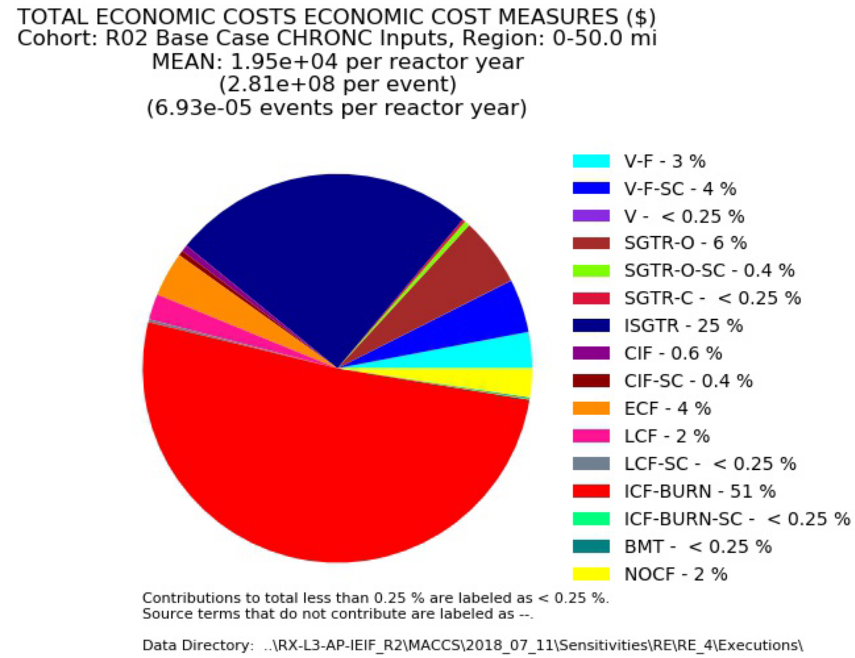
Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**8.1E+04**	**2.0E+04**	**0.240**
V-F	1.0E-07	5.9E+09	5.9E+09	0.995
V-F-SC	2.0E-07	4.3E+09	4.3E+09	0.995
V	7.0E-08	6.3E+07	5.9E+07	0.930
SGTR-O	7.0E-08	1.6E+10	1.6E+10	0.994
SGTR-O-SC	2.0E-07	4.3E+08	4.3E+08	1.000
SGTR-C	7.0E-08	7.6E+08	7.0E+08	0.916
ISGTR	6.0E-07	8.4E+09	8.2E+09	0.973
CIF	7.0E-08	3.0E+09	1.5E+09	0.507
CIF-SC	7.0E-08	2.7E+09	1.2E+09	0.438
ECF	7.0E-08	1.6E+10	1.0E+10	0.644
LCF	2.9E-05	7.9E+08	1.4E+07	0.018
LCF-SC	3.0E-06	8.6E+07	1.5E+07	0.175
ICF-BURN	9.0E-06	5.3E+09	1.1E+09	0.209
ICF-BURN-SC	2.0E-06	9.3E+06	9.3E+06	1.000
BMT	8.0E-07	3.3E+07	2.1E+07	0.650
NOCF	2.4E-05	3.4E+07	2.0E+07	0.575

1. Results are a frequency-weighted sum of all release categories

2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



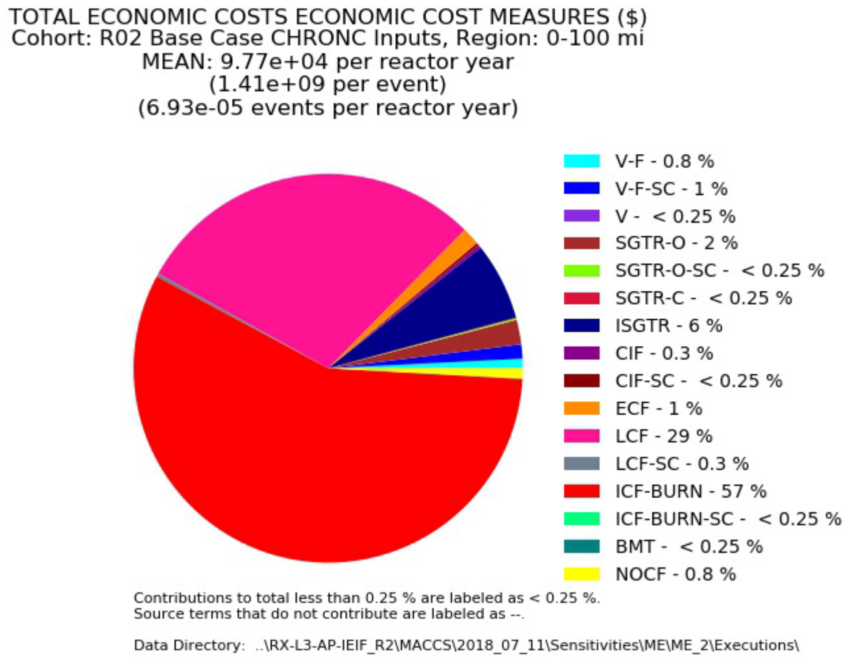
RE_4

Figure 4.6-9: Relative contribution of release categories to total economic costs, 0–50 mi (2015$): RE_4

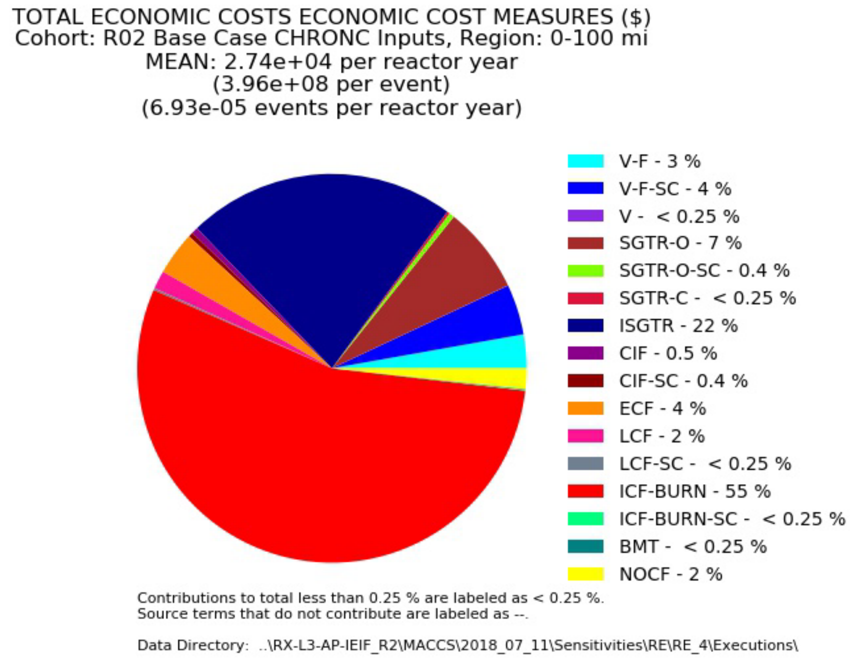
Table 4.6-8: Summary of total economic costs, 0–100 mi (2015$) (mean value across all weather trials): RE_4

Release Category	Frequency (/rcy)	Reference Case (ME_2)	RE_4	Fraction of Reference Case[2]
ALL[1] (per rcy)	**6.9E-05**	**9.8E+04**	**2.7E+04**	**0.281**
V-F	1.0E-07	7.7E+09	7.7E+09	0.996
V-F-SC	2.0E-07	5.8E+09	5.8E+09	0.997
V	7.0E-08	6.8E+07	6.3E+07	0.935
SGTR-O	7.0E-08	2.8E+10	2.8E+10	0.996
SGTR-O-SC	2.0E-07	6.0E+08	6.0E+08	1.000
SGTR-C	7.0E-08	9.9E+08	9.3E+08	0.933
ISGTR	6.0E-07	1.1E+10	1.0E+10	0.971
CIF	7.0E-08	3.7E+09	2.1E+09	0.556
CIF-SC	7.0E-08	3.2E+09	1.6E+09	0.498
ECF	7.0E-08	2.1E+10	1.4E+10	0.684
LCF	2.9E-05	9.9E+08	1.4E+07	0.015
LCF-SC	3.0E-06	8.8E+07	1.5E+07	0.171
ICF-BURN	9.0E-06	6.2E+09	1.7E+09	0.270
ICF-BURN-SC	2.0E-06	9.3E+06	9.3E+06	1.000
BMT	8.0E-07	3.3E+07	2.1E+07	0.650
NOCF	2.4E-05	3.4E+07	2.0E+07	0.575

1. Results are a frequency-weighted sum of all release categories
2. Fraction of reference case was calculated based on full-precision code outputs. Estimation of the ratio based on the rounded reference case and sensitivity results in this table may result in a larger (or smaller) difference than that computed from the actual code outputs.



Reference Case (ME_2)



RE_4

Figure 4.6-10: Relative contribution of release categories to total economic costs, 0–100 mi (2015$): RE_4

4.6.1.3 *Low-Dose Cancer Risk Estimation*

Inspection of the results for the estimated total economic costs arising from the use of a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem), shows that (as expected) there is no significant difference between the results of the reference case and the results for sensitivity case HE-2. For this sensitivity analysis, only a subset of weather trials was sampled in order to increase computational efficiency. For this case, the reference case values are therefore the results from ME_2 described above. These values were selected for the reference case to minimize confounding effects from weather sampling with the effect of using a dose truncation model. The ratio of the results of the reference and sensitivity case were 1.000 for all release categories and are therefore not reproduced here.[50]

[50] The ratio of HE_2 total economic costs to ME_2 total economic costs was 1.000 for all release categories with the exception of release categories V-F, V-F-SC, and LCF, for which a very slight (≤ 0.2%) reduction in total economic costs is observed. The reason for this slight reduction is unknown.

4.7 Results Summary

In general, reviews of a wide range of results suggest that for most accident sequences, warning times on the order of a few hours are sufficient to minimize the population subject to moderate or high doses in the early phase. Effectively, no populations were projected to receive the high doses needed for the induction of early health effects. This results in the bulk of the radiological exposure arising from reoccupation of land after decontamination and natural decay and weathering reduce exposures to levels below the habitability criteria assumed in the analysis (i.e., 2 rem in the year of the accident and 500 mrem per year in the years after the accident). These levels are in the low to very low dose range. As discussed in Volume 4, Annex X of (IAEA 2015), these levels would give rise to a small hypothetical additional lifetime risk of cancer (less than 0.1 percent). From an epidemiological standpoint, it is unlikely that the number of latent cancer fatalities attributable to radiation exposure from releases from a severe accident would be statistically observable above the expected number of cancer fatalities in the exposed population from all other causes (i.e., the excess cancer fatalities predicted are too few to allow the detection of a statistically significant difference in the cancer fatalities expected from other causes among the same population). The examination of early fatality risk (or comparably, the risk of high exposures) suggests that the extremely low likelihood of high doses to the offsite public are because of the following factors:

- Very low frequency of bypass events (ISLOCA or SGTR cases) that would generate relatively large and fast releases
- Relatively low frequency of adverse meteorological conditions (primarily stable, low wind speed conditions)
- Very sparse close-in population, which limits the likelihood of the wind blowing in the direction of a populated sector very close to the site
- Low likelihood of delayed and/or slow evacuation of the populations toward which the winds are blowing

These particular results are, of course, site-specific. Sites for which these factors are less applicable (i.e., higher close-in population densities, coupled with higher likelihood of slow or delayed evacuations) may experience a higher risk of elevated exposures.

The collective effects (collective effective dose, economic impacts, contaminated land area, affected population size, etc.) for this analysis appear largely to be driven by the magnitude of the release of the volatile fission products, such as cesium and iodine. Across a range of collective effects, there is a strong relationship between the projected mean value of these types of measures and the cesium release fraction. This likely explains the predominance of the LCF and ICF-BURN release categories for these types of results. Furthermore, different weather conditions, as represented by the weather bins used in the MACCS weather sampling algorithm, did not appear to contribute disproportionately to the mean value of these types of consequences. Because of this, the mean value of these types of results are not expected to be sensitive to the particular weather year chosen. Finally, it may be noted that for most scenarios, the total economic and affected population measures are very similar between 0–50 miles and 0–100 miles. This suggests that for all but the largest releases, the majority of the intermediate

phase affected population, as well as the majority of the economic costs, would be seen within 50 miles. Larger releases may result in a higher likelihood of intermediate-phase relocation beyond 50 miles, but the majority of the affected population is concentrated within 50 miles. Likewise, for higher magnitude releases (greater than approximately 1 percent Cs release fraction), the economic results begin to diverge, suggesting additional impacts beyond 50 miles. However, even for the largest releases, the differences are less than a factor of 2, suggesting that the majority of the economic impacts will occur within 50 miles for the types of source terms considered here.

The sensitivity analyses that were carried out that support these insights. A sensitivity analysis using a model that estimates cancer risk based only on annual individual doses greater than 0.05 Sv (5 rem), or lifetime individual doses greater than 0.1 Sv (10 rem), showed that projected cancer risks were greatly reduced. This supports the observation that most of the cancer risk in the base case arises from doses in the low to very low dose range for which the actual cancer risk is uncertain. The accident sequences (ISLOCA and SGTR accident sequences) which give rise to doses above this range are also those which gave rise to the (very low) early fatality risk in the base case, and have a frequency much lower than the containment failure release categories. The effect of terminating accident releases 36 hours after SAMG entry, which reduces the amount of radioactivity released (most notably from the late containment failure release categories), reduces the individual risk of latent cancer fatality within 10 miles, and also reduces the extent of contaminated land, populations subject to protective actions, and economic costs. However, accident release termination 36 hours after SAMG entry typically had little or no effect on the consequences of accidents that could lead to elevated doses (i.e., bypass events such as ISLOCA or SGTR), suggesting the potential for elevated doses is largely attributable to that the portion of the release that occurs within 36 hours after SAMG entry.

5 RISK INTEGRATION

5.1 Introduction

Figure 5.1-1 illustrates the overall logic and structure of traditional nuclear power plant PRA models, including the types of results that are produced at each of the following three analysis levels:

1. **Level 1 PRA: Accident frequency analysis.** The end-state of interest for a Level 1 PRA is core damage. A Level 1 PRA model therefore estimates total core damage frequency (CDF) using linked event tree and fault tree logic models that represent initiating events and response of mitigating systems.

2. **Level 2 PRA: Level 1 analysis plus accident progression, containment performance, and radiological release frequency analysis.** The end-state of interest for a Level 2 PRA is radiological release. A Level 2 PRA model therefore expands upon a Level 1 PRA model by adding severe accident phenomenological models and logic models that represent containment systems response to estimate radiological release category frequencies and various characteristics of the released radioactive material (commonly referred to as the *source term*).

3. **Level 3 PRA: Level 2 analysis plus offsite radiological consequence analysis.** Finally, the end-states of interest for a Level 3 PRA are various offsite radiological consequences. A Level 3 PRA model therefore expands upon a Level 2 PRA model by adding probabilistic consequence analysis models to quantify conditional measures of the offsite radiological health, environmental, or economic consequences, conditioned on the assumed occurrence of each postulated radiological release category and its representative source term that provides input to the offsite radiological consequence analysis.

In the context of a Level 3 PRA, the Risk Integration technical element—the subject of this section—includes the process of combining the results from the Level 2 radiological release frequency analysis with the corresponding results from the Level 3 offsite radiological consequence analysis to provide an overall characterization of the risk to the offsite public from a broad spectrum of postulated accidents involving the modeled nuclear power plant site. This overall characterization includes a characterization of uncertainty and identification of significant contributors to risk. Such contributors stem from events, phenomena, or modeling assumptions addressed in all three analysis levels within a Level 3 PRA. Notable examples of contributors that originate within each analysis level include (ASME/ANS 2015):

1. **Level 1: Accident Frequency Analysis**
   - Initiating events
   - Initiating event hazard groups
   - Random failure events involving structures, systems, or components (SSCs)
   - Common-cause failure (CCF) events involving SSCs
   - Human failure events (HFEs)

2. **Level 2: Radiological Release Frequency Analysis**
   - Phenomenological modeling assumptions
   - Containment fragilities
   - Random failure events involving SSCs
   - CCF events involving SSCs
   - HFEs

3. **Level 3: Offsite Radiological Consequence Analysis**
   - Meteorological data and atmospheric dispersion and deposition phenomena
   - Early (emergency) phase protective action modeling assumptions
   - Late-phase recovery action modeling assumptions
   - Dose-response modeling assumptions
   - Economic and land use data and modeling assumptions

The set of offsite public risk metrics that are addressed in this section are identified in Table 5.1-1. The remainder of this section is comprised of eight subsections. Section 5.2 addresses the methods and codes used to develop an overall characterization of the risk to the offsite public surrounding the reference nuclear power plant site from reactor accidents initiated by internal events or internal floods while the reactor is operating in the at-power plant operating state. Sections 5.3 through 5.8 presents results for offsite public risk metrics related to six main categories of offsite radiological consequences that relate to the selected set of offsite public risk metrics: (1) doses to the offsite public, (2) early health effects, (3) latent health effects, (4) land contamination, (5) affected population, and (6) economic costs. This section concludes with a summary in Section 5.9.

Table 5.1-1: Set of offfsite public risk metrics analyzed

No.	Offsite Public Risk Metric	Spatial Interval
1	Population Dose Risk	0–50 miles 0–100 miles
2	Population-Weighted Individual Early Fatality Risk	0-1.75 miles[a]
3	Total Early Fatality Risk	0–50 miles
4	Population-Weighted Individual Latent Cancer Fatality Risk	0–10 miles
5	Total Latent Cancer Fatality Risk	0–50 miles 0–100 miles
6	Land Contamination Risk (Area Exceeding 15 Ci/km^2 Cs-137)	0–50 miles 0–100 miles
7	Intermediate-Phase Population Relocation Risk	0–50 miles 0–100 miles
8	Economic Cost Risk	0–50 miles 0–100 miles

[a] *The 0-1.75 mile spatial interval is used to model the region out to 1 mile beyond the site boundary for the reference nuclear power plant site. The exclusion area boundary (EAB) is approximately 0.75 miles from the modeled reactor located at the origin of the radial spatial grid in MACCS.*

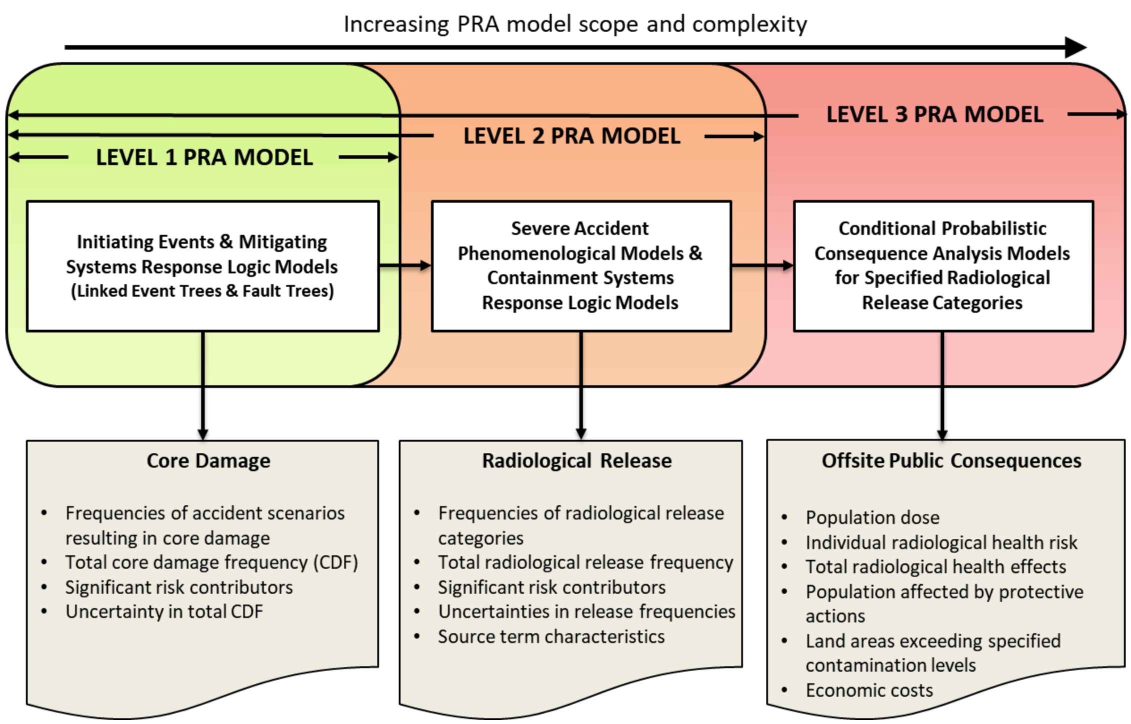


Figure 5.1-1: Overall logic and structure of traditional nuclear power plant PRA models

5.2 Methods and Codes

5.2.1 Introduction

This section addresses the methods and codes used to develop an overall characterization of the risk to the offsite public surrounding the reference nuclear power plant site from reactor accidents initiated by internal events or internal floods while the reactor is operating in the at-power plant operating state.

The overall objective of the Risk Integration technical element is to combine intermediate results from the Level 2 PRA (radiological release frequency analysis) with the corresponding results from the Level 3 PRA offsite radiological consequence analysis to characterize the overall risk to the offsite public using selected risk metrics (ASME/ANS 2015). From this objective, offsite public risk metrics are quantified by using various mathematical methods to combine two intermediate products of a Level 3 PRA for a commercial nuclear power plant:

1. **Radiological release category frequency estimates:** Estimates of radiological release category frequencies produced as part of the Level 2 PRA accident progression, containment performance, and radiological release frequency analysis.

2. **Conditional offsite public consequence estimates:** Estimates of conditional offsite public consequence metrics for each source term group modeled to represent each radiological release category, which are produced as part of the Level 3 PRA offsite radiological consequence analysis. This requires specification and estimation of a vector of consequence measures that represent the levels of damage or loss that can occur in terms of adverse outcomes of interest, conditioned on the assumed occurrence of a representative source term group.

Section 4 presented the results of the offsite radiological consequence analysis for a range of consequence metrics, including those used to calculate the selected set of offsite public risk metrics. Although the emphasis of Section 4 is on offsite radiological consequences, Section 4.1 through Section 4.6 include some results that are traditionally considered products of the Risk Integration technical element. These results will not be repeated in their entirety in Section 5; instead, the discussion that follows will point the reader to relevant sections, tables, or figures of Section 4, as appropriate.

5.2.2 Mean Annual Risk

One traditional Risk Integration product that is presented in Section 4 is mean annual risk. Mean annual risk is calculated by combining the mean values for the radiological release category frequencies with the mean conditional offsite public consequence metric results for the corresponding representative source term. In this context, the mean value represents the probability-weighted average for each conditional consequence metric over all weather trials resulting from the use of probabilistic sampling techniques within MACCS to sample from analyst-specified weather bins based on available meteorological data (Chanin et al. 1990;

Chanin et al. 1998a). Using this method, offsite public risk metrics are calculated using Equation 5.2-1:

$$R_m = \sum_{k=1}^{N_{RC}} [f_k \cdot (C_m|k)] \quad \text{Equation 5.2-1}$$

where:

- R_m = mean annual risk of consequence metric m (consequences per reactor-critical-year).[51]
- f_k = mean frequency of radiological release category k (per reactor-critical-year). The mean represents the probability-weighted average of the empirical probability distribution for the frequency of radiological release category k. As described in more detail in Section 5.2.4, this empirical probability distribution is generated using Monte Carlo sampling techniques to characterize the uncertainty in radiological release category frequencies due to uncertainties in input parameters for basic events in the Level 2 PRA logic models.
- $(C_m|k)$ = conditional mean over all weather trials for consequence metric m, given assumed occurrence of the representative source term for release category k. The mean represents the probability-weighted average of the empirical probability distribution for consequence metric m assuming the representative source term for release category k occurs. This empirical probability distribution is generated within MACCS by using weather sampling techniques to characterize the uncertainty in conditional consequences due to statistical variability over time in offsite weather conditions.
- m = index of selected conditional public consequence metrics.
- k = index of radiological release categories.
- N_{RC} = total number of modeled radiological release categories.

Tables 4-1 through 4-4 include the mean annual risk results for a range of consequence metrics, including those used to calculate the selected set of offsite public risk metrics discussed in Section 5. Section 4 also provides documentation of the methods and codes used to extract mean conditional consequence results from MACCS output files and to combine them with corresponding mean radiological release category frequency results to calculate mean annual risk.

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[51] Although the mean annual risk of consequence metric m is calculated consistent with current state of practice, it is important to recognize that this mean value may not accurately estimate the mean value that would be obtained if the empirical probability distribution for each radiological release category frequency were convoluted with its corresponding conditional empirical probability distribution for consequence metric m, rather than using the products of the mean values for these quantities.

5.2.3 Complementary Cumulative Distribution Function (CCDF) Curves

Another traditional Risk Integration product that is presented in Section 4 is the mean frequency-weighted CCDF curve[52] that illustrates the mean frequencies of exceeding different consequence levels for the selected set of offsite public consequence metrics. The variation in mean exceedance frequency along a single CCDF curve arises because: (1) accidents are probabilistic events that can occur in more than one way, with the likelihood and severity of an accident depending on the specific events that combine to give rise to it; and (2) the consequences of radiological releases from such accidents depend on the weather conditions (especially wind direction) that exist when radioactive materials are released to the environment following an accident. Each CCDF curve represents one way of characterizing aleatory uncertainty[53] by including: (1) the contributions from the full spectrum of modeled accident scenarios for a given PRA model structure and model parameters; and (2) the statistical variability over time in offsite weather conditions.

A mean frequency-weighted CCDF is calculated by combining the mean radiological release category frequencies with the corresponding conditional CCDF data that MACCS generates for each selected conditional offsite public consequence metric. Based on the results across all weather trials, MACCS calculates and reports 46 ordered data pairs of the form (consequence level, exceedance probability)—where the exceedance probability represents the relative frequency over all weather trials for which the specified consequence level was exceeded. Using this method, the mean frequencies of exceeding specified consequence levels for each selected offsite public consequence metric are calculated using Equation 5.2-2:

$$F_{mc} = \sum_{k=1}^{N_{RC}} [f_k \cdot (P_{mc}|k)] \qquad \text{Equation 5.2-2}$$

where:

- F_{mc} = mean frequency of exceeding consequence level c for consequence metric m over all weather trials and all modeled release categories (N_{RC}) (per reactor-critical-year).[54]
- f_k = mean frequency of radiological release category k (per reactor-critical-year). See Equation 5.2-1 for additional information about what this variable represents.

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52 A standard CCDF curve has probability instead of frequency on the ordinate (y-axis). The ordinate for the curves presented in Chapter 4 and Chapter 5 is frequency. Such curves are often referred to as *exceedance frequency curves* or *risk curves* and essentially answer the question "*How likely is it than an accident that results in consequences this severe or worse will occur?*" To be consistent with previous nuclear power plant PRA studies, these curves will be referred to as CCDF curves in this project.

53 Aleatory uncertainty is explained in more detail in Section 5.2.4.

54 As with mean annual risk, although the mean frequency of exceeding consequence level c for consequence metric m over all weather trials and all modeled release categories is calculated consistent with current state of practice, it is important to recognize that this mean value may not accurately estimate the mean value that would be obtained if the empirical probability distribution for each radiological release category frequency were convoluted with its corresponding conditional empirical probability distribution for consequence metric m.

- $(P_{mc}|k)$ = conditional probability of exceeding consequence level c for consequence metric m over all weather trials, given assumed occurrence of representative source term for release category k.
- m = index of selected conditional public consequence metrics.
- c = index of consequence levels for each selected conditional public consequence metric.
- k = index of radiological release categories.
- N_{RC} = total number of modeled radiological release categories.

Section 4.1 through Section 4.6 include figures that present the mean frequency-weighted CCDF curves for the selected set of offsite public consequence metrics. These figures include mean frequency-weighted CCDF curves for individual radiological release categories, as well as the total mean frequency-weighted CCDF curve across all modeled radiological release categories that is obtained using Equation 5.2-2.

5.2.4 Characterization of Uncertainty in Risk Results

As stated in Section 5.2.1, offsite public risk metrics are quantified by using various mathematical methods to combine two intermediate products of a Level 3 PRA for a commercial nuclear power plant: (1) estimates of radiological release category frequencies; and (2) estimates of conditional offsite public consequence metrics, conditioned on the assumed occurrence of a particular radiological release category. Each of these intermediate products used to calculate an offsite public risk metric represents an uncertain output quantity. This means the offsite public risk metrics that are calculated by mathematically combining two uncertain quantities are also uncertain output quantities. This section describes the methods and codes used to characterize uncertainty in offsite public risk metrics.

5.2.4.1 *Uncertainties in Nuclear Power Plant PRA Models*

Uncertainties in PRA models arise from many sources. However, these many sources have traditionally been organized into two principal types: (1) aleatory uncertainty, and (2) epistemic uncertainty. *Aleatory uncertainty* arises from inherent randomness within modeled systems or phenomena (Drouin et al. 2017). Within a PRA logic model, basic events are assumed to arise from random processes with defined probability models (e.g., binomial, Poisson); these probability models can be used to calculate basic event frequencies or probabilities for specified input parameter values. The PRA logic model and the underlying probability distributions for calculating basic event frequencies or probabilities thus represents an explicit characterization of aleatory uncertainty for the modeled system. In addition, probabilistic consequence analysis codes can use probabilistic sampling techniques to sample from analyst-specified weather bins based on available meteorological data to account for two important sources of aleatory uncertainty in offsite radiological consequence models: (1) when an accident will occur within a specified time period (typically one year of reactor operation for nuclear power plant applications); and (2) what the prevailing weather conditions will be for the duration of any radiological release(s) to the environment (Chanin et al. 1990, 1998a).

Epistemic uncertainty arises from limitations in our state of knowledge about modeled systems or phenomena. There are three subtypes of epistemic uncertainty associated with PRA models (Drouin et al. 2017):

1. **Parameter Uncertainty.** Parameter uncertainty arises from imperfect data and knowledge in the estimation of input parameters for probability distributions used to quantify basic event frequencies or probabilities in the PRA logic model. This assumes that the selection of the probability distribution used to model the aleatory uncertainty for a basic event is agreed upon; if uncertainty exists about this selection, it is more appropriately considered model uncertainty, which is described next. Parameter uncertainty is typically characterized by using probability distributions to represent the subjective degree of belief about the possible values of these input parameters.

2. **Model Uncertainty.** Model uncertainty arises from imperfect knowledge about systems or phenomena modeled in a PRA. Since uncertainty can exist about which modeling approach is most appropriate, this can lead to uncertainty in the PRA results. Model uncertainty can also arise from uncertainty about: (1) the structure of a PRA logic model, or (2) the probability distribution used to model the aleatory uncertainty for a basic event in the PRA logic model. It is important to note that some epistemic uncertainties arising from imperfect knowledge about the values of some input parameters for phenomena represented in the Level 2 PRA logic model, the Level 2 PRA severe accident progression models, or the Level 3 PRA offsite radiological consequence models are treated as model uncertainties rather than parameter uncertainties. Model uncertainties are typically addressed by using sensitivity analyses to determine the sensitivity of the PRA results to using any reasonable alternative modeling approaches.

3. **Completeness Uncertainty.** Completeness uncertainty arises from limitations in the scope of the PRA model. Known risk contributors can be excluded from the PRA model due to technology or resource limitations or because their contribution to the overall risk results is believed to be negligible. These uncertainties can be addressed by supplementing the PRA with additional bounding analyses to demonstrate their impact is not significant. By contrast, unknown risk contributors are excluded because their potential existence has not yet been recognized. These uncertainties are typically addressed using defense-in-depth principles. Although it can be viewed as a special type of model uncertainty, completeness uncertainty is typically treated separately because it reflects an unanalyzed contribution to risk that is difficult, if not impossible, to quantify.

This section is limited in scope and addresses the propagation and analysis of parameter uncertainties to characterize the uncertainty in offsite public risk metrics due to epistemic uncertainties in input parameters for basic events in the Level 1 and Level 2 PRA logic models. For the L3PRA project, the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) software (Smith & Wood 2011) has been selected for developing these logic models. Consistent with current state of practice and with the NUREG-1150 study (NRC 1990), epistemic uncertainties in input parameters for the offsite radiological consequence model developed within MACCS will generally not be propagated or analyzed. Instead, the

conditional offsite public consequence metric results calculated for each weather trial and assumed representative source term—which collectively account for the aleatory uncertainty in conditional offsite public consequence metrics due to statistical variability in offsite weather conditions over time—will be treated as fixed when propagating and analyzing the epistemic uncertainties in the Level 1 and Level 2 PRA logic model parameters. Therefore, the uncertainty analysis documented in this section focuses on propagating and analyzing the uncertainty in end-state frequencies (i.e., radiological release category frequencies) due to epistemic uncertainties in the input parameters for the basic events modeled in the Level 1 and Level 2 PRA logic models. It is expected that model uncertainties and completeness uncertainties will be addressed in other elements of the L3PRA project using state-of-practice methods (e.g., sensitivity analyses or bounding analyses), as appropriate, and subject to schedule and resource constraints.

Although the uncertainty analysis for the L3PRA project is limited in scope, results from other NRC-sponsored studies can be used to obtain insights into the potential impacts on risk results of some sources of uncertainty that are not analyzed as part of the L3PRA project. For example, uncertainty analyses were performed for specific accident scenarios that were modeled and analyzed as part of the Peach Bottom, Surry, and Sequoyah SOARCA studies (SNL 2016; SNL 2015; SNL 2019). These analyses assumed the occurrence of specified conditions in the progression of the modeled accident scenarios. The high-level objectives for these uncertainty analyses include:

- Develop insights into the overall sensitivity of SOARCA results to uncertainty in inputs.
- Identify the most influential input parameters for accidental releases of radioactive materials and offsite radiological consequences.
- Demonstrate the application of an uncertainty analysis methodology that could be used in future source term, consequence analysis, or nuclear power plant Level 3 PRA studies.

The SOARCA uncertainty analyses involved varying multiple uncertain model parameters in the severe accident progression and offsite radiological consequence models using Monte Carlo sampling of parameter probability distributions. Subject matter experts were consulted to determine the most important uncertain parameters in accident progression, release of radioactive materials, and offsite radiological consequence models for variation. Multiple statistical regression techniques were then used to quantify uncertainty and to determine which parameters have the greatest influence on the results. Insights from these uncertainty analyses offer an additional perspective that can be used to supplement the limited treatment of uncertainty in the L3PRA project.

5.2.4.2 *Sampling Techniques for Uncertainty Propagation: Monte Carlo versus Latin Hypercube Sampling*

The current state of practice for propagating input parameter uncertainties to quantitatively estimate the epistemic uncertainty in an output risk metric of interest (e.g., end-state frequency) relies on using either of two random or pseudo-random sampling techniques that are available

within SAPHIRE: (1) Monte Carlo sampling, or (2) Latin hypercube sampling (LHS) (Cullen & Frey 1999; Morgan & Henrion 1990; Smith & Wood 2011).

Monte Carlo sampling refers to the traditional technique for using random or pseudo-random numbers to sample from an input parameter's epistemic probability distribution. Monte Carlo sampling techniques are—at least in principle—entirely random. Therefore, any given sample value may fall anywhere within the range of the input parameter's probability distribution. With enough trials, Monte Carlo sampling reproduces the probability distributions for the input parameters. However, a potential problem with Monte Carlo sampling when a small number of trials is used is that random sampling variability can cause samples from input parameter probability distributions to cluster together, thereby resulting in a sample that is not representative of the full probability distribution (Cullen & Frey 1999; Morgan & Henrion 1990; Smith & Wood 2011).

By contrast, LHS stratifies the input parameter probability distributions. With this sampling technique, each input parameter epistemic probability distribution is divided into a specified number of non-overlapping intervals that each have an equal probability. The number of non-overlapping, equal-probability intervals is set to coincide with the number of LHS samples to be obtained or trials to be run. For example, if 1,000 samples trials will be run to obtain convergence, each input parameter epistemic probability distribution will be divided into 1,000 intervals such that the area within each interval has an equal probability. A random or pseudo-random value is then sampled from each interval of each input parameter's probability distribution. Each sampled value for each input parameter is then paired in a random way with a sampled value from each of the other input parameters for which an epistemic probability distribution has been specified. This stratified random sampling technique overcomes the potential clustering problem and closely reproduces the input parameter probability distributions with a fewer number of trials than would be needed if Monte Carlo sampling were used. The net effect is that use of LHS techniques can achieve stable results in output risk metrics with a faster convergence rate (i.e., a greater reduction in the variance of the output risk metric as the number of trials is increased) when compared to use of Monte Carlo sampling. In practice, the LHS technique requires only a quarter of the sample size of Monte Carlo sampling to achieve similar accuracy. However, for some distributions, it can take longer to generate a random number using the LHS technique than for Monte Carlo sampling. Still, LHS techniques can often substantially reduce the time required to propagate parameter uncertainties, while achieving a comparable level of accuracy in the output risk metric results (Cullen & Frey 1999; Morgan & Henrion 1990; Smith & Wood,2011).

5.2.4.3 *NUREG-1150 Approach to Parameter Uncertainty Propagation*

For the NUREG-1150 Level 3 PRAs (NRC 1990), parameter uncertainties were characterized by using probability distributions to represent the subjective degree of belief about the possible values of input parameters in the Level 1 and Level 2 PRA logic models. A computer code external to the codes used to perform the Level 1 and Level 2 frequency analyses and the Level 3 offsite radiological consequence analyses was used to implement an LHS algorithm involving

Equation 5.2.3

about 200 equally likely trials to propagate these parameter uncertainties. In the NUREG-1150 study, mean annual risk was quantified using Equation 5.2-3 (NRC 1990):

$$R_{mn} = \sum_h \sum_i \sum_j \sum_k f_n(IE_h) \cdot P_n(IE_h \rightarrow PDS_i|IE_h) \cdot P_n\left(PDS_i \rightarrow APB_j|PDS_i\right) \cdot P_n(APBj \rightarrow STG_k|APBj) \cdot C_m\,|STG_k$$

where:

- R_{mn} = mean annual risk of consequence measure m for LHS trial n (consequences per reactor-critical-year).
- $f_n(IE_h)$ = frequency of initiating event h for LHS trial n (per reactor-critical-year).
- $P_n(IE_h \rightarrow PDS_i|IE_h)$ = conditional probability of initiating event h resulting in plant damage state i for LHS trial n.
- $P_n\left(PDS_i \rightarrow APB_j|PDS_i\right)$ = conditional probability of plant damage state i resulting in accident progression bin j for LHS trial n.
- $P_n(APBj \rightarrow STG_k|APBj)$ = conditional probability that accident progression bin j is partitioned into source term group k for LHS trial n.
- $C_l|STG_k$ = conditional expected value of consequence measure m for source term group k.
- h = index of initiating events.
- i = index of plant damage states.
- j = index of accident progression bins.
- k = index of source term groups.
- m = index of consequence measures.
- n = index of LHS trials.

Using this approach resulted in about 200 sample values for the frequency of each radiological release category and representative source term group (STG_k)—which is the intermediate product that results from combining the first four terms of Equation 5.2-3 ($f_n(IE_h) \cdot P_n(IE_h \rightarrow PDS_i|IE_h) \cdot P_n\left(PDS_i \rightarrow APB_j|PDS_i\right) \cdot P_n(APBj \rightarrow STG_k|APBj)$) and summing over the h through j indices. Each of these sample values for the source term group frequencies ($f_n(STG_k)$) were then combined with a fixed set of conditional offsite radiological consequence metric results for the corresponding representative source term group ($C_m|STG_k$).[55] and summed over the k indices to produce about 200 sample values for each of the selected offsite public risk metrics (R_{mn}).

A similar approach was used to construct sets of frequency-weighted CCDF curves comprised of about 200 curves used to characterize the epistemic uncertainty in exceedance frequency for different consequence levels due to imperfect knowledge about the input parameters in the

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55 As previously stated, epistemic uncertainties in input parameters for the offsite radiological consequence model were not propagated nor analyzed as part of the NUREG-1150 study.

Level 1 and Level 2 PRA logic models. Each frequency-weighted CCDF was calculated using Equation 5.2-4:

$$F_{mcn} = \sum_{k=1}^{N_{RC}}[f_n(STG_k) \cdot (P_{mc}|STG_k)] \qquad \text{Equation 5.2-4}$$

where:

- F_{mcn} = frequency of exceeding consequence level c for consequence metric m over all weather trials and all modeled release categories (N_{RC}) for LHS trial n (per reactor-critical-year).
- $f_n(STG_k)$ = frequency of source term group k for LHS trial n (per reactor-critical-year).
- $(P_{mc}|STG_k)$ = conditional probability of exceeding consequence level c for consequence metric m over all weather trials, given assumed occurrence of source term group k.
- m = index of selected conditional public consequence metrics.
- c = index of consequence levels for each selected conditional public consequence metric.
- k = index of source term groups.
- N_{RC} = total number of modeled source term groups.

5.2.4.4 *Approach to Parameter Uncertainty Propagation for the L3PRA Project*

As with the NUREG-1150 study, parameter uncertainties for the L3PRA project are characterized by using probability distributions to represent the subjective degree of belief about the possible values of input parameters in the Level 1 and Level 2 PRA logic models. The main differences between the NUREG-1150 approach and the approach to performing parameter uncertainty propagation to characterize the epistemic uncertainty in selected offsite public risk metrics for the L3PRA project are driven by technical advances that have been realized in computing capabilities and in the analytical tools used for performing nuclear power plant PRAs since the 1990s. Key differences arising from these technical advances that influence the approach to parameter uncertainty propagation include:

1. **Development of integrated Level 1 and Level 2 PRA logic models within SAPHIRE.** To address technical limitations in available analytical tools, the NUREG-1150 study required use of so-called *pinch points* or interfaces that resulted in the compression and loss of information between the initiating event and radiological release. In particular, two pinch points were used between initiating events and source term groups that characterized radiological release categories and that provided input to the Level 3 offsite radiological consequence analyses: (1) plant damage states (PDSs), and (2) accident progression bins (APBs). This approach required the use of transition matrices, with entries that represented the conditional probabilities of particular events or pinch point categories resulting in a subsequent pinch point category. These transition matrices and conditional probabilities—which are shown in Equation 5.2-3—had to be reproduced and mathematically manipulated with each LHS trial to generate about 200 sample values for the frequency of each radiological release category and representative source term group. By contrast, the L3PRA project has leveraged advances in SAPHIRE to develop fully integrated Level 1 and Level 2 PRA logic models. This means cut set information is passed directly from the Level 1 to the

Level 2 models without any information compression or loss, thereby enabling direct quantification of the frequencies of defined radiological release categories without the need for transition matrices or additional computation using external computer codes.

2. **Sampling techniques can be implemented directly within SAPHIRE.** For the NUREG-1150 study, implementing the LHS sampling technique required use of external computer codes. However, to estimate the epistemic uncertainty in output results due to basic event input parameter uncertainties, SAPHIRE can use either of two random or pseudo-random sampling techniques: (1) Monte Carlo sampling, or (2) LHS. To implement these techniques, SAPHIRE uses a fixed set of minimal cut sets for an end-state of interest that is determined by the underlying logic structure. For all basic events in this set of minimal cut sets, SAPHIRE randomly samples the parameters from their probability distributions and uses sampled parameter values to calculate: (1) the basic event frequency or probability, (2) the end-state frequency, and (3) basic event importance measures. This sampling and calculation procedure is repeated for a specified number of trials to generate empirical probability distributions for the end-state frequency and basic event importance measures.
3. **A far greater number of sampling trials can be used, thereby producing more stable and accurate results.** Due to limitations in computational resources, only about 200 LHS trials were performed for each nuclear power plant site evaluated in the NUREG-1150 study. For the L3PRA project, parameter uncertainties have been propagated within SAPHIRE using a Monte Carlo sampling technique with a sample size of 1,000 trials. This significant increase in the sample size for generating empirical probability distributions produces results that are more stable and accurate than those that could be obtained for the NUREG-1150 study.

Aside from these key differences, the overall philosophy and approach to propagating input parameter uncertainties to characterize the resulting uncertainties in radiological release category frequencies and selected offsite public risk metrics is much like that of NUREG-1150. The first step was to perform random sampling to generate empirical probability distributions for radiological release category frequencies within SAPHIRE and to export the results to EXCEL. As previously stated, the Monte Carlo sampling technique was implemented within SAPHIRE to generate empirical probability distributions comprised of 1,000 sample values for defined radiological release category frequencies as part of the Level 2 PRA for this project (see Appendix C, Section 3 of [NUREG, 2019]).[56] The results for each sampling trial, which SAPHIRE retains following the completion of the uncertainty propagation, were then exported to an EXCEL file.

[56] The 1,000 sample values for each radiological release category frequency that are used for this version of the Level 3 PRA are based on an earlier version of the Level 2 PRA, and therefore do not exactly match the sample values for the final Level 2 PRA uncertainty analysis. The final Level 2 PRA uncertainty analysis incorporated some corrections to the correlation categorization for some common cause failure events, as well as reduced error factors for some high failure probability basic events that resulted in some Monte Carlo samples being discarded by SAPHIRE during the uncertainty analysis, because the sampled probability exceeded 1.0. These differences do not significantly impact the Level 3 PRA uncertainty analysis results.

The second step was to test for convergence. For all release categories, convergence is reached at 1,000 samples. More details can be found in the detailed uncertainty report [NRC 2020].

The third step was to generate sets of CCDF curves for selected offsite public risk metrics. Each of the sample values for the radiological release category frequencies was combined with the conditional CCDF data that MACCS generates for each selected conditional offsite public consequence metric to produce an equivalent number of CCDF curves for each of the selected offsite public risk metrics. In particular, for each Monte Carlo sample trial n, the frequencies of exceeding specified consequence levels for each selected offsite public consequence metric were calculated using Equation 5.2-5:

$$F_{mcn} = \sum_{k=1}^{N_{RC}} [f_{kn} \cdot (P_{mc}|k)] \qquad \text{Equation 5.2-5}$$

where:

- F_{mcn} = frequency of exceeding consequence level c for consequence metric m over all weather trials and all modeled release categories (N_{RC}) for Monte Carlo sample trial n (per reactor-critical-year).
- f_{kn} = frequency of radiological release category k for Monte Carlo sample trial n (per reactor-critical-year).
- $(P_{mc}|k)$ = conditional probability of exceeding consequence level c for consequence metric m over all weather trials, given assumed occurrence of representative source term for radiological release category k.
- m = index of selected conditional public consequence metrics.
- c = index of consequence levels for each selected conditional public consequence metric.
- k = index of radiological release categories.
- N_{RC} = total number of modeled radiological release categories.

Consistent with current state of practice and with the NUREG-1150 study, epistemic uncertainties in input parameters for the offsite radiological consequence model developed within MACCS were not propagated nor analyzed. Instead, the conditional offsite public consequence metric results calculated for each weather trial and assumed representative source term—which collectively account for the aleatory uncertainty in conditional offsite public consequence metrics due to statistical variability in offsite weather conditions over time—were treated as fixed in the uncertainty propagation.

A generic example of a set of 5,000 frequency-weighted CCDF curves that were created using this approach is provided in Figure 5.2-1. This example is representative of the sets of CCDF curves that will be presented throughout Section 5 to characterize risk and uncertainty for the selected set of offsite public consequence metrics. As previously stated, the variation in exceedance frequency along the horizontal axis of a single CCDF curve characterizes aleatory uncertainty by including: (1) the contributions from the full spectrum of modeled accident scenarios for a given PRA model structure and model parameters, and (2) the statistical

variability over time in offsite weather conditions. By contrast, variation in the exceedance frequency along the vertical axis across CCDF curves characterizes epistemic uncertainty arising from imperfect knowledge about the values of input parameters in the Level 1 and Level 2 PRA logic models.

In addition to the frequency-weighted CCDF curves created from the Monte Carlo sample trials as described above, Figure 5.2-1 includes four CCDF curves that correspond to the following summary statistics: (1) mean (expected value), (2) median (50^{th} percentile), (3) 95^{th} percentile, and (4) 5^{th} percentile. These curves were constructed by first calculating these summary statistics for the distribution of Monte Carlo sample values at each specified consequence level, and then fitting a single curve through the points that correspond to a particular summary statistic. For example, the mean frequency-weighted CCDF curve was constructed by first calculating the mean exceedance frequency value for the distribution of Monte Carlo sample values at each specified consequence value, and then fitting a single curve through each of the mean exceedance frequency values across all specified consequence levels.

These summary statistic curves can be used to characterize the epistemic uncertainty in exceedance frequencies for specified consequence levels arising from imperfect knowledge about the values of input parameters in the Level 1 and Level 2 PRA logic models. For example, in Figure 5.2-1, the mean curve indicates that the frequency of accidents that result in more than 1×10^4 consequence units is about 4×10^{-5} per reactor-critical-year. This is equivalent to stating that accidents that result in more than 1×10^4 consequence units are expected to occur about once every 25,000 years. Since the mean and median curves are roughly equivalent, there is about an equal probability that the true frequency of accidents that result in more than 1×10^4 consequence units is above (50 percent probability) or below (50 percent probability) 4×10^{-5} per reactor-critical-year. Using the 5^{th} and 95^{th} percentile curves, we can state that the probability that the true frequency of accidents that result in more than 1×10^4 consequence units is at or below 1×10^{-5} per reactor-critical-year is 5 percent and the probability that the true frequency of accidents that result in more than 1×10^4 consequence units is at or below 1×10^{-4} per reactor-critical-year is 95 percent. Alternatively, we can state that there is a 90 percent probability that the true frequency of accidents that result in more than 1×10^4 consequence units is bounded by the interval 1×10^{-4} per reactor-critical-year to 1×10^{-5} per reactor-critical-year. Likewise, we can state that there is a 90 percent probability that accidents that result in more than 1×10^4 consequence units will occur about once every 10,000 to 100,000 years. Therefore, there is about an order of magnitude in uncertainty about the true exceedance frequency at a consequence level of 1×10^4 consequence units.

It is important to keep in mind when interpreting this example and the sets of frequency-weighted CCDF curves that these curves only include the contribution to epistemic uncertainty arising from imperfect knowledge about the values of input parameters in the Level 1 and Level 2 PRA logic models. These curves do not include the following contributions to epistemic uncertainty: (1) epistemic uncertainty arising from imperfect knowledge about the values of input parameters in Level 2 PRA severe accident phenomenological models or Level 3 PRA offsite

radiological consequence models;[57] (2) epistemic uncertainty arising from imperfect knowledge about systems or phenomena modeled in the PRA (model uncertainty); and (3) epistemic uncertainty arising from limitations in the scope of the PRA model (completeness certainty).

5.2.5 Significant Contributors to Risk

A fundamental product of the Risk Integration technical element is the identification and characterization of significant contributors to risk. Such contributors stem from events, phenomena, or modeling assumptions addressed in all three analysis levels within a Level 3 PRA. Notable examples of contributors that originate within each analysis level were listed in Section 5.1.

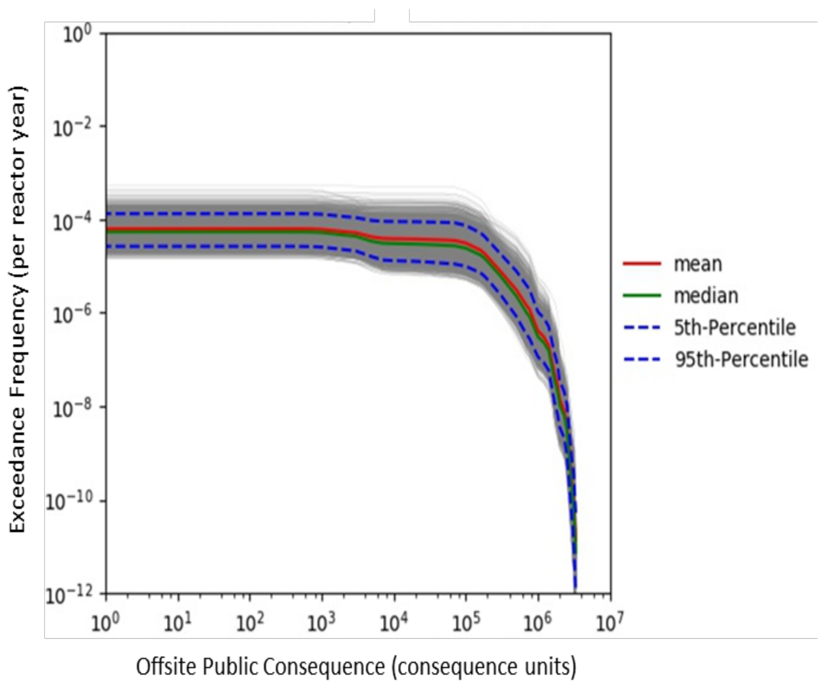

Figure 5.2-1: Generic example of a set of frequency-weighted CCDF curves

As previously stated, although the emphasis of Section 4 is on offsite radiological consequences, Section 4.1 through Section 4.6 include some results that are traditionally considered products of the Risk Integration technical element. These results include identification and characterization of some significant contributors to risk. In particular, Section

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[57] As previously stated, some epistemic uncertainties arising from imperfect knowledge about the values of some input parameters for phenomena represented in the Level 2 PRA logic model, the Level 2 PRA severe accident progression models, or in the Level 3 PRA offsite radiological consequence models are treated as model uncertainties rather than parameter uncertainties. Therefore, the uncertainties associated with these input parameters were not propagated through the Level 2 PRA logic model when characterizing the epistemic uncertainty in radiological release category frequencies. The contributions of these input parameter uncertainties for some phenomenological events are thus not included in the sets of frequency-weighted CCDF curves.

4.1 through Section 4.6 identify and characterize the following types of significant contributors to risk:

- Classes of accident sequences and radiological release categories that contribute significantly to the mean annual risk for each selected offsite public risk metric.
- Combinations of radiological release categories and weather bins (offsite weather conditions) that contribute significantly to selected offsite public consequence and risk metrics.
- Early (emergency) phase protective action and late-phase recovery action modeling assumptions that contribute significantly to selected offsite public consequence and risk metrics.

For this reason, the identification and characterization of significant contributors to risk described in Section 5 will focus on identifying and characterizing significant contributors to risk stemming from the events, phenomena, or modeling assumptions in the Level 1 and Level 2 PRA logic models. Notable examples of such contributors include:

- Initiating events
- Random failure events involving SSCs
- CCF events involving SSCs
- HFEs
- Phenomenological modeling assumptions

5.2.5.1 *Composite Fussell-Vesely Importance Measure*

As stated in Section 5.2.3, to address technical limitations in available analytical tools, the NUREG-1150 study required use of so-called *pinch points* or interfaces that resulted in the compression and loss of information between the initiating event and radiological release. By contrast, the L3PRA project has leveraged advances in SAPHIRE to develop fully integrated Level 1 and Level 2 PRA logic models. This means cut set information is passed directly from the Level 1 to the Level 2 models without any information compression or loss, thereby enabling direct quantification of the frequencies of defined radiological release categories without the need for transition matrices or additional computation using external computer codes. The fully integrated Level 1 and Level 2 PRA logic models in SAPHIRE can thus be used to calculate importance measures for basic events with respect to each radiological release category frequency.

To further leverage these technical advances, the project staff defined a new importance measure that can be used to identify significant contributors to risk stemming from the events, phenomena, or modeling assumptions in the Level 1 and Level 2 PRA logic models for each selected offsite public risk metric. This new importance measure, termed the *composite Fussell-Vesely (FV) importance measure*, is based on the standard FV importance measure that SAPHIRE can calculate for each basic event in the fully integrated Level 1 and Level 2 PRA

logic model.[58] The standard FV importance measure for a particular basic event represents the relative contribution to the total end-state frequency from accident scenarios that include that basic event.

From this, the composite FV importance measure is calculated by coupling Equation 5.2-6 and 5.2-7:

$$w_k^m = \frac{R_k^m}{R_{total}^m} \qquad \text{Equation 5.2-6}$$

$$FV_b^m = \sum_{k=1}^{N_{RC}} w_k^m \cdot FV_b^k \qquad \text{Equation 5.2-7}$$

where:

- m = index of selected offsite public risk metrics.
- k = index of radiological release categories.
- N_{RC} = total number of modeled radiological release categories.
- b = index of basic events in the integrated Level 1 and Level 2 PRA logic model.
- R_k^m = absolute contribution to mean annual risk for offsite public risk metric m from radiological release category k.
- R_{total}^m = total mean annual risk for offsite public risk metric m from all modeled radiological release categories.
- w_k^m = relative contribution from radiological release category k to the total mean annual risk for offsite public risk metric m.
- FV_b^k = Standard Fussell-Vesely importance measure value for basic event b with respect to the frequency of radiological release category k. This value represents the relative contribution to the total frequency of radiological release category k from accident scenarios that include basic event b.
- FV_b^m = Composite Fussell-Vesely importance measure value for basic event b with respect to the total mean annual risk for offsite public risk metric m. This value represents the relative contribution to the total mean annual risk for offsite public risk metric m from accident scenarios that include basic event b.

Thus, the composite FV importance measure for a particular basic event is used to represent the relative contribution to the total mean annual risk for each selected offsite public risk metric

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[58] The use of FV importances is a convenient means to indicate the relative risk contribution of individual basic events (or sets of mutually exclusive basic events) and is a common PRA practice (which is used in this study). However, it should be noted that due to simplifications in the quantification routines used to calculate FV importances in typical PRA software, inaccuracies can manifest themselves when relatively high basic event failure probabilities are involved (as is often the case with Level 2 PRAs).

from accident scenarios that include that basic event. In practice, this composite FV importance measure is calculated as a weighted sum of the standard FV importance measure for the basic event with respect to each radiological release category frequency, weighted by the relative contribution of each radiological release category to the mean annual risk for each selected offsite public risk metric.

The ASME/ANS Level 1/LERF PRA Standard (ASME/ANS 2013) defines a risk-significant basic event as a basic event with an FV importance measure value that is greater than 0.005 ($FV > 0.005$). The results for this composite FV importance measure are thus compared against this criterion to identify basic events in the integrated Level 1 and Level 2 PRA logic models that represent significant contributors to total mean risk for selected offsite public risk metrics.

Identification of significant contributors to risk stemming from the events, phenomena, or modeling assumptions in the Level 1 and Level 2 PRA logic models was thus accomplished in five steps:

1. Select the offsite public risk metric m.
2. Use Equation 5.2-6 to calculate w_k^m, the relative risk contribution from each radiological release category k to the total mean annual risk for offsite public risk metric m.
3. Export the standard FV importance measure value for each basic event b with respect to the frequency of each radiological release category k (FV_b^k) from SAPHIRE to an EXCEL file.
4. Use Equation 5.2-7 and the relative risk contributions from each radiological release category k to weight the standard FV importance measure value for each basic event b with respect to the frequency of radiological release category k and to calculate the composite FV importance measure value for each basic event b with respect to offsite public risk metric m. This calculation was performed in Python.
5. Identify all basic events with a composite FV importance measure value greater than 0.005. The set of basic events that satisfy this criterion constitutes the significant contributors to risk for offsite public risk metric.

5.2.6 Clarification on Risk Integration Results

In Section 4, individual release categories with a frequency less than 0.1 percent of total release category frequency (RCF) are assigned an RCF equal to 0.1 percent of total RCF (i.e., 7.0E-08/rcy), so as not to over-state the accuracy of the Level 2 PRA model. However, it should be noted that all the risk integration results provided in Section 5 are based on the actual RCFs for each individual release category, except where reference is specifically made to information obtained from Section 4. For example, the CCDF curves provided in the following subsections and the composite FV importance measures provided in the tables of Appendix B are all based on the actual RCFs for each release category, while the percent contributions of individual

release categories to the different risk metrics in the following subsections are based on the values provided in Section 4.

Two final points to note:

- All results are provided for an accident at a single unit—a subsequent report in this series addresses multi-unit risk.
- Some figures in Section 5 label the risk metric results in terms of “per reactor year (/ry).” In actuality, these risk metric results are in terms of “per reactor-critical-year (/rcy).”

5.3 Doses to the Offsite Public

Collective total effective dose (i.e., population dose) risk is calculated and reported over two spatial intervals around the reference nuclear power plant: (1) 0–50 miles, and (2) 0–100 miles. The 0–50 mile region was selected to be consistent with the default interval specified in the NRC's regulatory analysis guidelines (NRC 2004) for calculating collective total effective dose in cost-benefit analyses performed as part of regulatory, backfit, or environmental analyses. However, lessons learned from the 2011 nuclear accident at the Fukushima Daiichi Nuclear Power Station (IAEA 2015; NAS/NRC 2014; The ASME Presidential Task Force on Response to Japan Nuclear Power Plant Events 2012)—together with subsequent probabilistic consequence analysis studies (Barto et al. 2014)—suggest that there could be significant societal impacts on the offsite population at distances greater than 50 miles from a nuclear power plant site. Therefore, the project staff decided to calculate collective total effective dose over both the 0–50 mile and 0–100 mile spatial intervals around the reference nuclear power plant site. This approach, which is applied to all other offsite public risk metrics that measure risks of societal impacts, enables the project staff to: (1) determine whether using an alternative spatial interval would result in different risk insights or provide additional perspectives, (2) provide insights about trends in offsite public risks as a function of distance from the reference nuclear power plant site, and (3) establish a precedent for not relying on a default practice of using the 0–50 mile spatial interval.

The summary results in Table 4-1 showed a frequency-weighted mean annual collective total effective dose risk within 50 miles and 100 miles of 9.9 and 20 person-rem per reactor-critical-year, respectively. Those values were obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequency.

5.3.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.3-1a and Figure 5.3-1b display sets of CCDF curves that illustrate the frequencies of exceeding specified levels of collective total effective dose within 50 miles and 100 miles of the reference nuclear power plant site, respectively. These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA. As shown in the figures, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 2×10^5 person-rem. This indicates the likelihood of exceeding collective total effective dose levels beyond these values becomes increasingly less likely as the collective total effective dose increases.

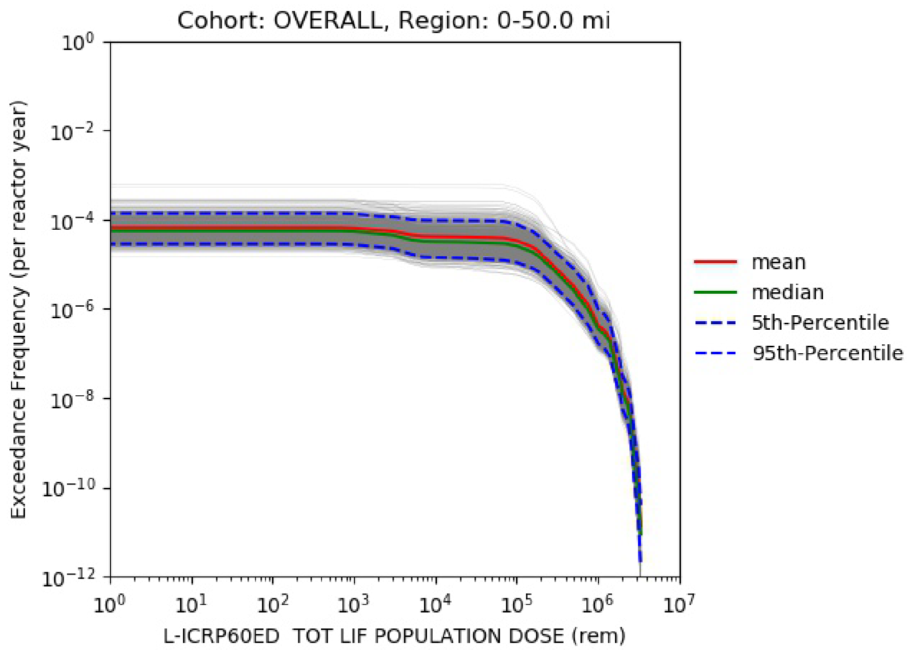

Figure 5.3-1a: CCDF curves for collective total effective dose (0–50 Miles)

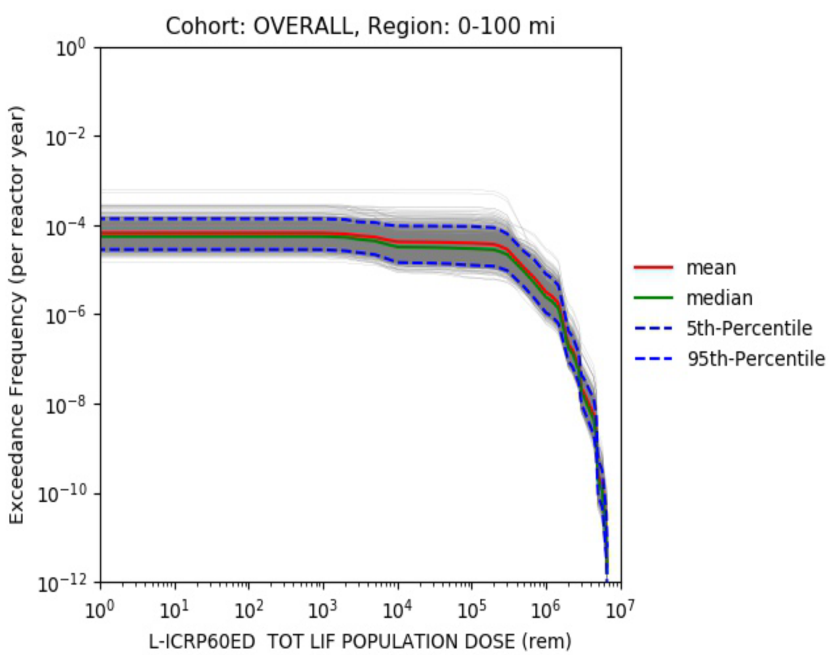

Figure 5.3-1b: CCDF curves for curves for collective total effective dose (0–100 Miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.3-1a and Table 5.3-1b summarize the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of

exceeding specified collective total effective doses within 50 miles and 100 miles of the reference nuclear power plant site, respectively. These tables show that there is little difference between the results for the 0–50 and 0–100 mile regions, except for fairly large collective total effective doses (e.g., $1x10^6$ person-rem). Examination of Figure 5.3-1a and 5.3-1b reveals that the maximum population dose across all modeled accident scenarios and all weather trials was about $3x10^6$ for the 0–50 mile region and about $6x10^6$ for the 0–100 mile region. This suggests that there are low-frequency accidents that could result in significant collective total effective doses that go beyond 50 miles.

Table 5.3-1a: Mean and 90% confidence intervals for exceedance frequencies of specified collective total effective dose levels (0–50 Miles)

Population Dose (0–50 miles) (person-rem)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^4$	$4.1x10^{-5}$ per reactor-critical-year (1 in 24,000 years)	$1.4x10^{-5}$ – $9.5x10^{-5}$ per reactor-critical-year (1 in 11,000 to 71,000 years)
$1x10^5$	$3.3x10^{-5}$ per reactor-critical-year (1 in 30,000 years)	$1.1x10^{-5}$ – $7.8x10^{-5}$ per reactor-critical-year (1 in 13,000 to 91,000 years)
$1x10^6$	$4.3x10^{-7}$ per reactor-critical-year (1 in 2.3 million years)	$1.7x10^{-7}$ –$1.0x10^{-6}$ per reactor-critical-year (1 in 1 million to 5.9 million years)

Table 5.3-1b: Mean and 90% confidence intervals for exceedance frequencies of specified collective total effective dose levels (0–100 Miles)

Population Dose (0–100 miles) (person-rem)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^4$	$4.2x10^{-5}$ per reactor-critical-year (1 in 24,000 years)	$1.4x10^{-5}$ – $9.6x10^{-5}$ per reactor-critical-year (1 in 10,000 to 71,000 years)
$1x10^5$	$3.9x10^{-5}$ per reactor-critical-year (1 in 26,000 years)	$1.3x10^{-5}$ – $9.3x10^{-5}$ per reactor-critical-year (1 in 11,000 to 77,000 years)
$1x10^6$	$3.1x10^{-6}$ per reactor-critical-year (1 in 320,000 years)	$1.1x10^{-6}$ – $7.9x10^{-6}$ per reactor-critical-year (1 in 130,000 to 900,000 years)

5.3.2 Significant Contributors to Risk

Figure 4.1-3a and Figure 4.1-3b illustrate the relative contributions of each modeled radiological release category to the mean annual risk of collective total effective dose within 50 miles and 100 miles, respectively. These figures show that mean annual risk of collective total effective dose within 50 or 100 miles is dominated by two radiological release categories: (1) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment

are not mitigated significantly by sprays or water pools (LCF); and (2) an intermediate containment failure release category in which the containment fails hours after vessel breach, due to a global deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN). These two radiological release categories collectively contribute well over 90 percent of the risk from these two metrics.

Table B.1a and Table B.1b in the appendix include the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance greater than 0.005 for mean annual risk of population dose within 50 miles and 100 miles, respectively. Virtually all of these basic events are in common for both risk metrics. Examples of the most significant contributors include failure of manual extension of turbine-driven auxiliary feedwater (TD-AFW) in a station blackout (SBO) scenario, which has the largest composite FV for both 50 and 100 miles (contributing approximately 46 percent to these risk measures); many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. Note, some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

Examination of Tables B.1a and B.1b also reveals that SBO sequences contribute approximately 80 percent to mean annual risk of collective total effective dose both within 50 and 100 miles. Over half of this contribution comes from common cause failure (CCF) of either both reserve auxiliary transformer (RAT) input breakers to open or both safeguards load sequencers to operate. Both of these CCFs result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable.

Also as can be seen from Tables B.1a and B.1b, loss of nuclear service cooling water (NSCW) sequences (leading to reactor coolant pump seal LOCAs) and medium LOCAs contribute approximately another 7 percent and 5 percent, respectively, to these two risk metrics.

5.4 <u>Early Health Effects</u>

Two offsite public risk metrics pertaining to early health effects are calculated and reported. Population-weighted individual early fatality risk (0–1.8 miles) measures the average annual risk to individuals within 1 mile of the site boundary of dying within 1 year from acute exposures to radiation due to modeled accidental releases of radiological materials from the reference nuclear power plant site. Results for this metric can be compared to the average individual early fatality risk quantitative health objective (QHO) to obtain insights related to the NRC's safety goal policy (NRC 1986). As shown in Table 4-2, the frequency-weighted mean annual population-weighted individual early fatality risk within 1 mile of the site boundary is 3.4×10^{-13} per reactor-critical-year. That value was obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequencies.

Total early fatality risk (0–50 miles) measures total annual risk to society of deaths among the population within 50 miles occurring within 1 year from acute exposures to radiation due to modeled accidental releases of radiological materials from the reference nuclear power plant site. As shown in Table 4-2, the frequency-weighted mean annual risk of total early fatalities within 50 miles is 8.7×10^{-12} per reactor-critical-year. That value was obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequencies.

5.4.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.4-1 displays sets of CCDF curves that illustrate the frequencies of exceeding specified levels of population-weighted individual early fatality risk within 1 mile of the site boundary. Likewise, Figure 5.4-2 displays sets of CCDF curves that illustrate the frequencies of exceeding specified numbers of early fatalities within 50 miles. These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA.

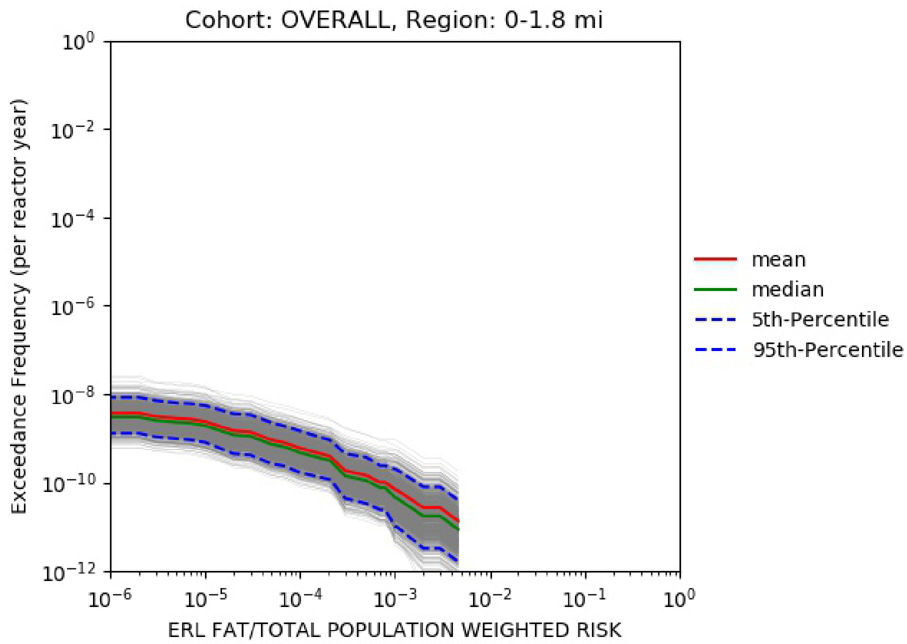

Figure 5.4-1: CCDF curves for population-weighted individual early fatality risk (0–1.8 miles)

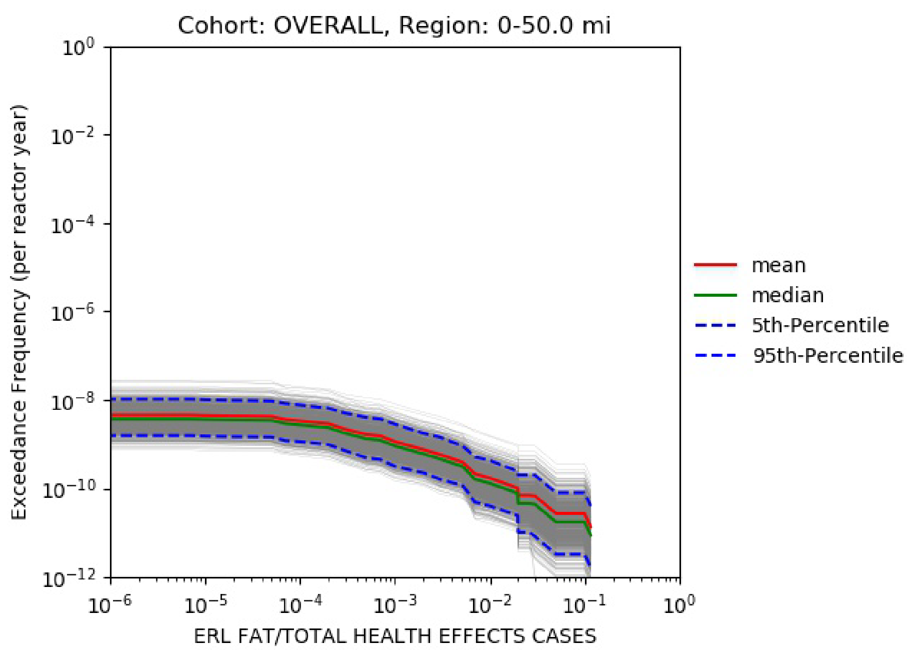

Figure 5.4-2: CCDF curves for total early fatality risk (0–50 miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.4-1 summarizes the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding specified levels of population-weighted early fatality risk within 1 mile of the site boundary. Table 5.4-2 shows similar information for the frequencies of exceeding specified levels of total early fatality risk within 50 miles of the plant.

Table 5.4-1: Mean and 90% confidence intervals for exceedance frequencies of specified levels of population-weighted individual early fatality risk (0–1.8 miles)

Population-Weighted Early Fatality Risk (0–1.8 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^{-6}$	$3.8x10^{-9}$ per reactor-critical-year (1 in 260 million years)	$1.3x10^{-9}$ – $8.5x10^{-9}$ per reactor-critical-year (1 in 120 million to 770 million years)
$1x10^{-5}$	$2.4x10^{-9}$ per reactor-critical-year (1 in 420 million years)	8.1x10–10 – $5.5x10^{-9}$ per reactor-critical-year (1 in 180 million to 1.2 billion years)
$1x10^{-4}$	6.1x10–10 per reactor-critical-year (1 in 1.6 billion years)	1.7x10–10 – $1.5x10^{-9}$ per reactor-critical-year (1 in 670 million to 5.9 billion years)

Table 5.4-2: Mean and 90% confidence intervals for exceedance frequencies of specified levels of total early fatality risk (0–50 Miles)

Total Early Fatality Risk (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^{-6}$	$4.6x10^{-9}$ per reactor-critical-year (1 in 220 million years)	$1.6x10^{-9}$ – $1.0x10^{-8}$ per reactor-critical-year (1 in 100 million to 630 million years)
$1x10^{-5}$	$4.5x10^{-9}$ per reactor-critical-year (1 in 220 million years)	$1.5x10^{-9}$ – $1.1x10^{-8}$ per reactor-critical-year (1 in 91 million to 670 million years)
$1x10^{-4}$	$3.4x10^{-9}$ per reactor-critical-year (1 in 290 million years)	$1.1x10^{-9}$ – $7.7x10^{-9}$ per reactor-critical-year (1 in 130 million to 910 million years)

To put these results in perspective, a very large asteroid capable of causing a global catastrophe is expected to occur about once every 50 million years, with a 90 percent probability interval that ranges from a frequency of once every 20 million years to once every 1 billion years (Garrick 2008). These results suggest that the magnitude of average individual early fatality risks within 1 mile of the reference nuclear power plant site is extremely low.

Note that Figure 5.4-2 shows that the maximum number of early fatalities observed across all modeled accident scenarios and across all weather trials was essentially less than one fatality.

Although it seems counterintuitive to have a non-integer result for the total number of early fatalities that is less than one, this result occurs because of two features of the MACCS code that affect modeling of the population surrounding a nuclear power plant site: (1) the assignment of populations to discrete spatial grid elements can cause a fraction of an individual to be assigned to a specific grid element, and (2) population fractions are assigned to each of the modeled emergency-response cohorts, which means a non-integer number can be assigned to each cohort. For these reasons, it is possible for an accident scenario to result in more than zero but less than one early fatality.

From Figure 5.4-2, we can estimate that the mean frequency of exceeding one early fatality within 50 miles of the reference nuclear power plant site is less than 1×10^{-11} per reactor-critical-year. Put another way, accidents that result in at least one early fatality are expected to occur no more frequently than about once every 100 billion years, further indicating that the early fatality risk to the population surrounding the reference nuclear power plant site is extremely low. The staff recognizes the inherent uncertainty in these very low numbers; however, the conclusion remains that the probability of an early fatality is very small.

5.4.2 Significant Contributors to Risk

Figure 4.2-3 illustrates the relative contributions of each modeled radiological release category to the mean annual population-weighted individual early fatality risk within 1 mile of the site boundary and to the mean annual risk of total early fatalities within 50 miles. This figure shows that mean annual risk of early health effects is dominated by four radiological release categories: (1) a release category in which a release occurs from the RCS to the auxiliary building via an ISLOCA with the break point not submerged and auxiliary building failure (V-F); (2) a release category in which a release occurs from the RCS to the auxiliary building via an ISLOCA with the break point submerged and auxiliary building failure (V-F-SC); (3) a release category in which a release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage (ISGTR); and (4) a release category in which a release from the RCS to the environment occurs via one or more ruptured SG tubes, where the rupture occurred prior to core damage, the release is not mitigated by water above the break point on the secondary side of the affected SG, and one or more secondary-side relief valves are either kept open during the release as a deliberate action or fail in the open position (SGTR-O). Collectively, these four release categories contribute virtually all of the risk from these two metrics.

Table B.2 in the appendix includes the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual population-weighted individual early fatality risk within 1 mile of the site boundary. Table B.3 in the appendix includes the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual risk of total early fatalities within 50 miles. The same set of 71 basic events were considered significant contributors to both offsite public risk metrics related to early health effects. The most significant contributors to mean annual population-weighted individual early fatality risk within 1 mile of the site boundary and to mean annual risk of total early fatalities within 50 miles involve various

failures leading to an ISLOCA. ISLOCAs contribute nearly 90 percent to these two risk metrics, the vast majority associated with failures of residual heat removal (RHR) system components.

The largest individual composite FV for both mean annual population-weighted individual early fatality risk within 1 mile of the site boundary and mean annual risk of total early fatalities within 50 miles is the occurrence of an ISLOCA in one of the two RHR system hot leg suction lines, contributing 60 percent to these two risk metrics. The next largest composite FV for both metrics is the basic event representing the probability that a large ISLOCA break is not submerged or scrubbed, which results in a much larger source term. This event contributes 56 percent to both risk metrics.

5.5 Latent Health Effects

Three offsite public risk metrics pertaining to latent health effects are calculated and reported. As discussed in Section 3.6, these results assume a linear non-threshold model for latent health effects. The population-weighted individual latent cancer fatality risk (0–10 miles) obtained from the MACCS Type 8 output reports the average annual risk to individuals within 10 miles of dying from cancers caused by doses arising from modeled accidental releases of radiological materials from the reference nuclear power plant site. This result, by weighting health effects cases across the entire 10-mile population, reflects the occurrence of exposures relative to the distribution of population around the site. Results for this metric can be compared to the average individual latent cancer fatality risk QHO to obtain insights related to the NRC's safety goal policy (NRC 1986). As shown in Table 4-3, the mean annual population-weighted individual latent cancer fatality risk within 10 miles is 2.5×10^{-8} per reactor-critical-year.

Total latent cancer fatality risk (0–50 miles, 0–100 miles) obtained from the MACCS Type 1 output measures the total annual risk to society of cancer deaths among the population within 50 miles and 100 miles caused by excess lifetime exposure to radiation due to modeled accidental releases of radiological materials from the reference nuclear power plant site. As shown in Table 4-3, the mean annual risk of total latent cancer fatalities within 50 miles and 100 miles is 5.2×10^{-3} and 1.1×10^{-2} per reactor-critical-year, respectively.

5.5.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.5-1 displays sets of CCDF curves that illustrate the frequencies of exceeding specified levels of population-weighted latent cancer fatality risk within 10 miles. These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA. As shown in the figure, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 5×10^{-4}. This indicates the likelihood of exceeding population-weighted latent cancer fatality risk levels beyond these values becomes increasingly less likely as the risk level increases. Likewise, Figure 5.5-2a and Figure 5.5-2b display sets of CCDF curves that illustrate the frequencies of exceeding specified numbers of latent cancer fatalities within 50 miles and 100 miles, respectively. As shown in the figures, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 1×10^{2}. This indicates the likelihood of exceeding latent cancer fatalities beyond these values becomes increasingly less likely as the number of fatalities increases.

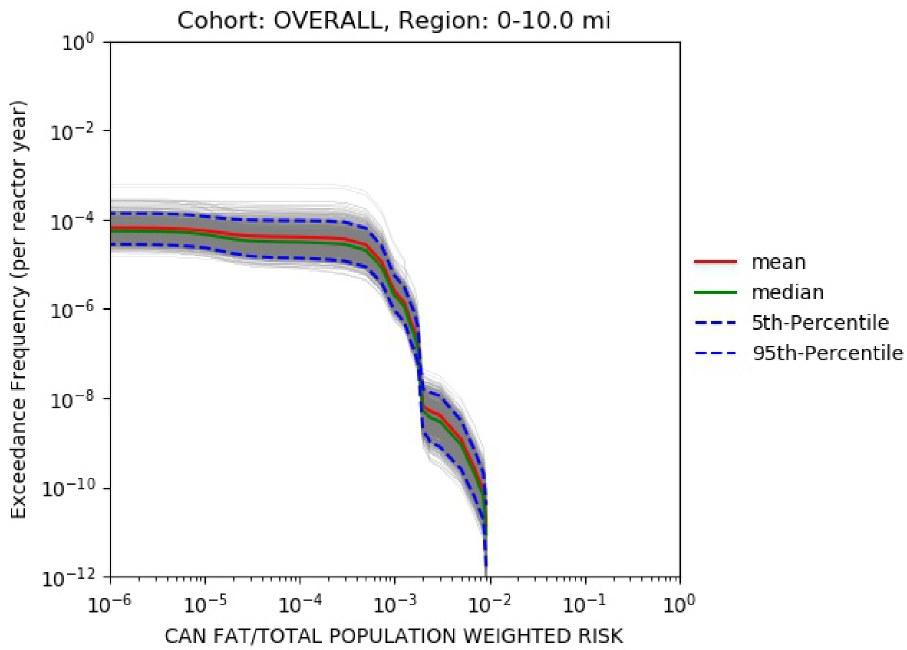

Figure 5.5-1: CCDF curves for population-weighted latent cancer fatality risk (0–10 miles)

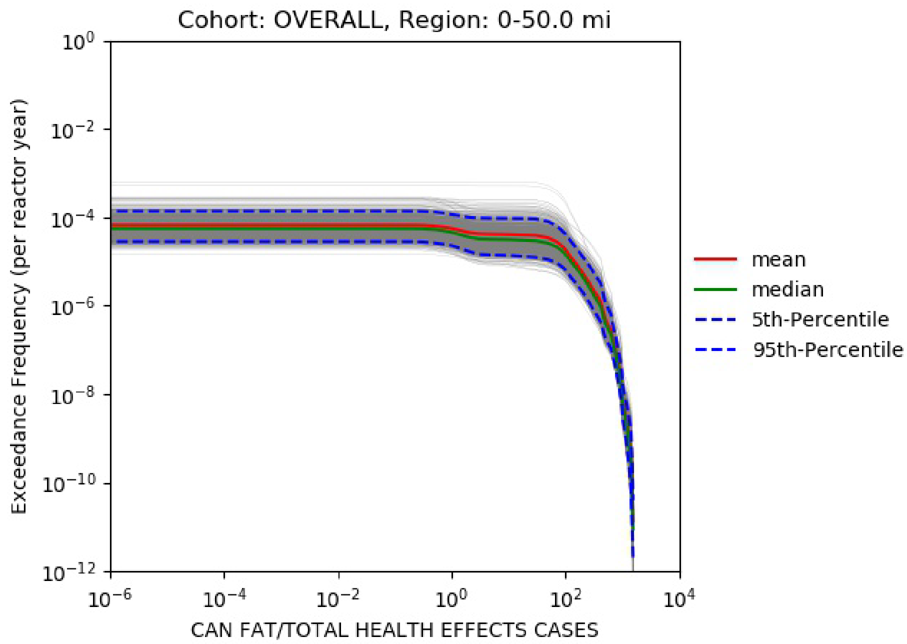

Figure 5.5-2a: CCDF curves for total latent cancer fatality risk (0–50 miles)

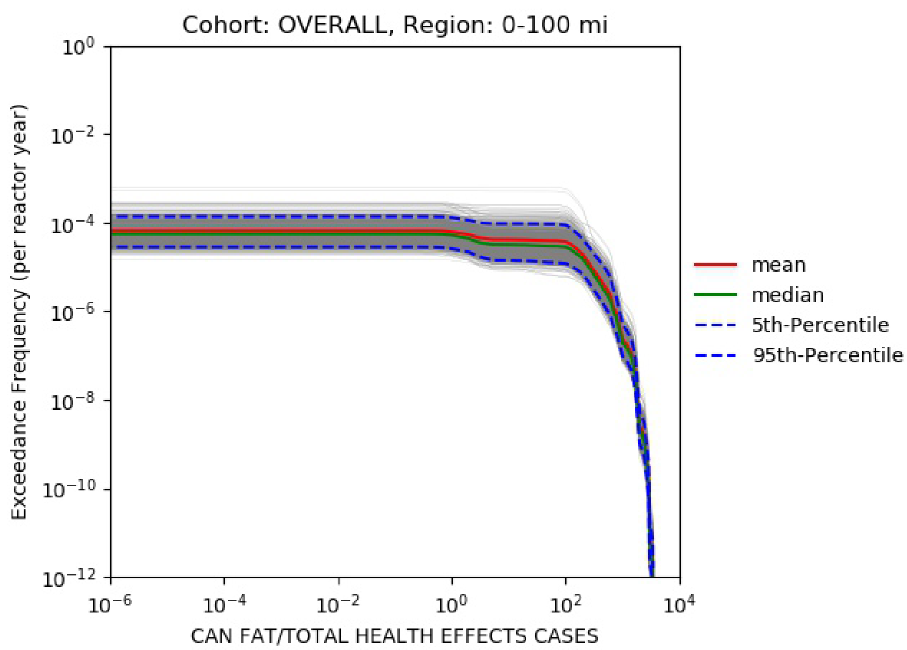

Figure 5.5-2b: CCDF curves for total latent cancer fatality risk (0–100 miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.5-1 summarizes the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding specified

levels of population-weighted latent cancer fatality risk within 10 miles. Table 5.5-2 and Table 5.5-3 summarize the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding specified numbers of latent cancer fatalities within 50 miles and 100 miles, respectively.

Table 5.5-1: Mean and 90% confidence intervals for exceedance frequencies of specified levels of population-weighted individual latent cancer fatality risk (0–10 miles)

Population-Weighted Individual Latent Cancer Fatality Risk (0–10 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^{-6}$	$6.5x10^{-5}$ per reactor-critical-year (1 in 15,000 years)	$2.8x10^{-5}$ – $1.4x10^{-4}$ per reactor-critical-year (1 in 7,000 to 36,000 years)
$1x10^{-5}$	$5.6x10^{-5}$ per reactor-critical-year (1 in 18,000 years)	$2.3x10^{-5}$ – $1.2x10^{-4}$ per reactor-critical-year (1 in 8,000 to 43,000 years)
$1x10^{-4}$	$4.1x10^{-5}$ per reactor-critical-year (1 in 24,000 years)	$1.4x10^{-5}$ – $9.3x10^{-5}$ per reactor-critical-year (1 in 11,000 to 71,000 years)

Table 5.5-2: Mean and 90% confidence intervals for exceedance frequencies of specified numbers of latent cancer fatalities (0–50 miles)

Latent Cancer Fatalities (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1	$5.6x10^{-5}$ per reactor-critical-year (1 in 18,000 years)	$2.3x10^{-5}$ – $1.2x10^{-4}$ per reactor-critical-year (1 in 8,000 to 43,000 years)
10	$4.1x10^{-5}$ per reactor-critical-year (1 in 24,000 years)	$1.4x10^{-5}$ – $9.4x10^{-5}$ per reactor-critical-year (1 in 11,000 to 71,000 years)
100	$1.8x10^{-5}$ per reactor-critical-year (1 in 56,000 years)	$6.4x10^{-6}$ – $4.1x10^{-5}$ per reactor-critical-year (1 in 24,000 to 160,000 years)

Table 5.5-3: Mean and 90% confidence intervals for exceedance frequencies of specified numbers of latent cancer fatalities (0–100 miles)

Latent Cancer Fatalities (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1	$6.2x10^{-5}$ per reactor-critical-year (1 in 16,000 years)	$2.6x10^{-5}$ – $1.3x10^{-4}$ per reactor-critical-year (1 in 8,000 to 38,000 years)
10	$4.2x10^{-5}$ per reactor-critical-year (1 in 24,000 years)	$1.4x10^{-5}$ – $9.5x10^{-5}$ per reactor-critical-year (1 in 11,000 to 71,000 years)

100	3.7×10^{-5} per reactor-critical-year (1 in 27,000 years)	1.2×10^{-5} – 8.8×10^{-5} per reactor-critical-year (1 in 11,000 to 83,000 years)

5.5.2 Significant Contributors to Risk

Figure 4.3-6 illustrates the relative contributions of each modeled radiological release category to the mean annual population-weighted individual latent cancer fatality risk within 10 miles. The figure shows that mean annual population-weighted individual latent cancer fatality risk within 10 miles is dominated by two radiological release categories: (1) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment are not mitigated significantly by sprays or water pools (LCF); and (2) an intermediate containment failure release category in which the containment fails hours after vessel breach, due to a global deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN). These two radiological release categories collectively contribute well over 90 percent to the mean annual population-weighted individual latent cancer fatality risk within 10 miles, and are also the same two release categories that dominate mean annual risk of population dose within 50 miles and 100 miles. The values provided in Table 4-3 can be used to demonstrate that these same two radiological release categories also contribute well over 90 percent to the mean annual risk of total latent cancer fatalities within 50 miles and 100 miles.

Table B.4 in the appendix includes the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual population-weighted individual latent cancer fatality risk within 10 miles. Table B.5a and Table B.5b in the appendix include the basic events that have a composite FV importance measure greater than 0.005 for mean annual risk of total latent cancer fatalities within 50 miles and 100 miles, respectively. The same 87 basic events are in common for these three risk metrics. The most significant contributors to mean annual population-weighted individual latent cancer fatality risk within 10 miles and to mean annual risk of total latent cancer fatalities within 50 and 100 miles are similar to those for other consequence metrics not associated with early health effects. As was seen previously with doses to the offsite public, examples of the most significant contributors include failure of manual extension of TD-AFW during an SBO scenario (contributing approximately 46 percent to these risk measures); many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. As previously noted, some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

Examination of Tables B.4, B.5a and B.5b also reveals that SBO sequences contribute approximately 80 percent to mean annual population-weighted individual latent cancer fatality risk within 10 miles and mean annual risk of total latent cancer fatalities within 50 miles and 100 miles. Over half of this contribution comes from CCF of either both RAT input breakers to open

or both safeguards load sequencers to operate. Both of these CCFs result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable.

Also as can be seen from Tables B.4, B.5a and B.5b, loss of NSCW sequences (leading to reactor coolant pump seal LOCAs) and medium LOCAs contribute approximately another 7 percent and 3-5 percent, respectively, to these risk metrics. Again, all of these results are consistent with those for other consequence metrics not associated with early health effects.

5.6 Land Contamination

Two offsite public risk metrics pertaining to land contamination are calculated and reported. Risk of land area exceeding 15 Ci/km^2 of Cs-137 concentration (0–50 miles, 0–100 miles) measures the total annual risk to society of land areas within 50 miles and 100 miles that exceed a concentration level of 15 Ci/km^2 for Cs-137 due to modeled accidental releases of radiological materials from the reference nuclear power plant site. These offsite public risk metrics that measure land contamination risk were selected for three main reasons: (1) NRC's mission is to protect people and the environment; (2) land can have inherent value to people, regardless of whether it is populated or it supports economic activity; and (3) risk metrics that measure economic costs and affected population may not capture risks to land areas around the reference nuclear power plant site that are not populated nor used for economic activity. A Cs-137 concentration level of 15 Ci/km^2 was selected for calculation and reporting because it is likely to require some level of restriction during the intermediate and recovery phases.

As shown in Table 4-4, the frequency-weighted mean annual risk of land area within 50 miles that exceeds 15 Ci/km^2 of Cs-137 concentration is $4.5x10^{-3}$ mi^2 per reactor-critical-year. The frequency-weighted mean annual risk of land area within 100 miles that exceeds 15 Ci/km^2 of Cs-137 concentration is $4.9x10^{-3}$ mi^2 per reactor-critical-year. Those values were obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequencies.

5.6.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.6-1a and Figure 5.6-1b display sets of CCDF curves that illustrate the frequencies of exceeding land areas within 50 miles and 100 miles, respectively, that exceed a Cs-137 concentration of 15 Ci/km^2. These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA. As shown in the figures, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 50 square miles (mi^2) for both the 0–50 and 0–100 mile regions. This indicates the likelihood of exceeding land areas that exceed a Cs-137 concentration of 15 Ci/km^2 beyond 50 mi^2 becomes increasingly less likely as the land area increases.

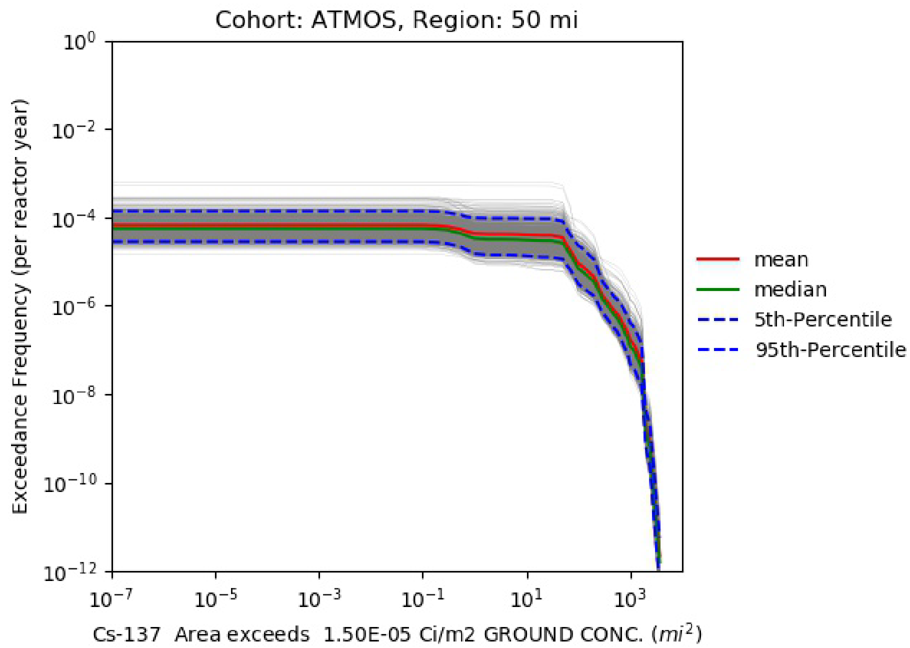

Figure 5.6-1a: CCDF curves for land area exceeding 15 Ci/mi² Cs-137 (0–50 miles)

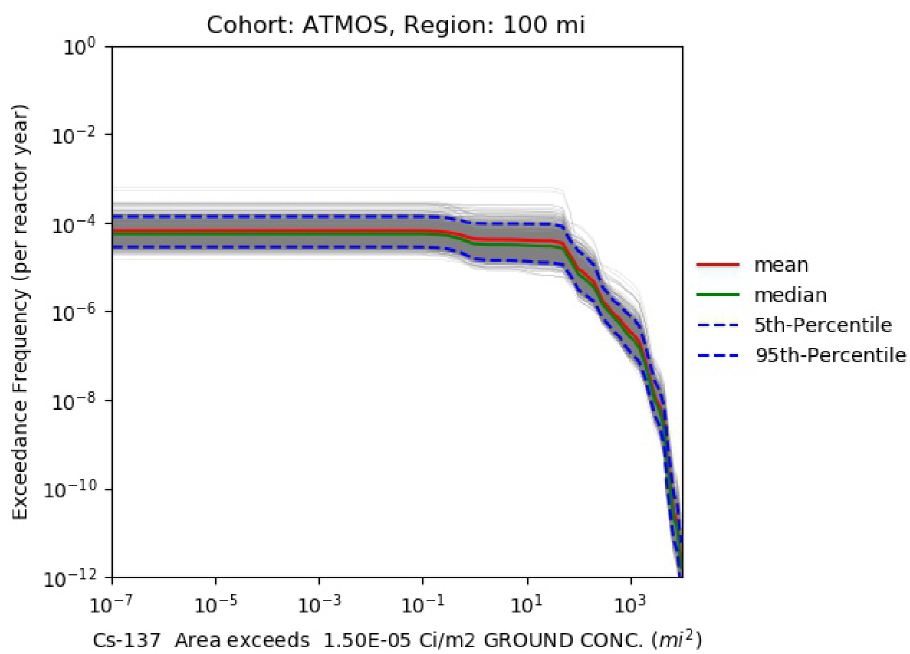

Figure 5.6-1b: CCDF curves for land area exceeding 15 Ci/mi² Cs-137 (0–100 miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.6-1 and Table 5.6-2 summarize the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding land areas within 50 miles and 100 miles, respectively, that exceed a Cs-137 deposition of 15 Ci/km^2.

Table 5.6-1: Mean and 90% confidence intervals for exceedance frequencies of land areas exceeding Cs-137 deposition of 15 Ci/km^2 (0–50 miles)

Land Area (mi^2) Exceeding Cs-137 Concentration of 15 Ci/km^2 (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1	4.3x10^{-5} per reactor-critical-year (1 in 23,000 years)	1.5x10^{-5} – 9.7x10^{-5} per reactor-critical-year (1 in 10,000 to 67,000 years)
10	4.0x10^{-5} per reactor-critical-year (1 in 25,000 years)	1.3x10^{-5} – 9.4x10^{-5} per reactor-critical-year (1 in 11,000 to 77,000 years)
100	9.1x10^{-6} per reactor-critical-year (1 in 110,000 years)	3.2x10^{-6} – 2.3x10^{-5} per reactor-critical-year (1 in 43,000 to 310,000 years)

Table 5.6-2: Mean and 90% confidence intervals for exceedance frequencies of land areas exceeding Cs-137 deposition of 15 Ci/km^2 (0–100 miles)

Land Area (mi^2) Exceeding Cs-137 Concentration of 15 Ci/km^2 (0–100 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1	4.3x10^{-5} per reactor-critical-year (1 in 23,000 years)	1.5x10^{-5} – 9.7x10^{-5} per reactor-critical-year (1 in 10,000 to 67,000 years)
10	4.0x10^{-5} per reactor-critical-year (1 in 25,000 years)	1.3x10^{-5} – 9.4x10^{-5} per reactor-critical-year (1 in 11,000 to 77,000 years)
100	9.1x10^{-6} per reactor-critical-year (1 in 110,000 years)	3.2x10^{-6} – 2.3x10^{-5} per reactor-critical-year (1 in 43,000 to 310,000 years)

5.6.2 Significant Contributors to Risk

Figure 4.4-1 illustrates the relative contributions of each modeled radiological release category to the mean annual risk of land area within 100 miles exceeding a Cs-137 concentration of 15 Ci/km^2. This figure shows that mean annual risk of land area within 100 miles exceeding a Cs-137 deposition of 15 Ci/km^2 is mainly dominated by three radiological release categories: (1) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment are not mitigated significantly by sprays or water pools (LCF); (2) an intermediate

containment failure release category in which the containment fails hours after vessel breach, due to a global deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN); and (3) a release category in which a release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage (ISGTR). Collectively, these three release categories contribute approximately 90 percent to the risk from these two metrics.

Table B.6a and Table B.6b in the appendix include the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual risk of land area within 50 miles and 100 miles, respectively, exceeding a Cs-137 concentration of 15 Ci/km^2. Virtually all of these basic events are in common for both risk metrics. The most significant contributors to mean annual risk of land area within 50 miles or 100 miles exceeding a Cs-137 concentration of 15 Ci/km^2 are similar to those seen for other consequence metrics not associated with early health effects. Examples of the most significant contributors include failure of manual extension of TD-AFW during an SBO scenario (contributing approximately 45 percent to these risk measures); many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. As previously noted, some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

Examination of Tables B.6a and B.6b also reveals that SBO sequences contribute nearly 80 percent to mean annual risk of land area within 50 miles and 100 miles exceeding a Cs-137 concentration of 15 Ci/km^2. Almost half of this contribution comes from CCF of either both RAT input breakers to open or both safeguards load sequencers to operate. Both of these CCFs result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable.

Also as can be seen from Tables B.6a and B.6b, loss of NSCW sequences (leading to reactor coolant pump seal LOCAs) and medium LOCAs contribute approximately another 6 percent and 5 percent, respectively, to these risk metrics. Again, all of these results are consistent with those for other consequence metrics not associated with early health effects.

5.7 Affected Population

Two offsite public risk metrics pertaining to affected population are calculated and reported. Risk of population affected by intermediate-phase relocation (0–50 miles, 0–100 miles) measures the total annual risk to society of the population within 50 miles and 100 miles being relocated in the intermediate phase to avert radiological dose due to modeled accidental releases of radiological materials from the reference nuclear power plant site.

Metrics that quantify the population affected by intermediate-phase relocation were selected to serve as a surrogate metric for the adverse public health and safety consequences associated with implementing protective actions to avert population dose. Inclusion of these indirect metrics enables a more complete characterization of the adverse offsite consequences attributable to a spectrum of accidental releases from the reference nuclear power plant site by illuminating tradeoffs between radiological and non-radiological health and safety risks. There are three principal reasons for selecting such an indirect measure in lieu of direct measures of adverse non-radiological health effects: (1) estimates of this indirect measure can be calculated using available technology, (2) this indirect measure can provide insights into a range of potential adverse non-radiological health effects attributable to implementing protective actions, and (3) results from a recent study suggest that the number of people relocated is a good and relatively straightforward to calculate proxy measure for societal disruption caused by potential nuclear accident scenarios (Bier et al. 2014).

The state of practice with respect to reporting metrics that quantify the population affected by protective actions in severe accident consequence analyses is evolving, with more contemporary NRC studies reporting such metrics. For example, as part of the technical basis for the containment protection and release reduction (CPRR) rulemaking for boiling-water reactors (BWRs) with Mark I-II containments, the staff reported metrics that quantified the population subject to long-term protective actions within 50 miles and 100 miles of the modeled sites (Barr et al. 2018). The L3PRA project decision to report measures of the total annual risk to society of the population within 50 miles and 100 miles being relocated in the intermediate phase to avert radiological dose due to modeled accidental releases of radiological materials from the reference nuclear power plant site is consistent with this evolving state of practice.

As shown in Table 4-4, the frequency-weighted mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles is 5.1×10^{-1} and 5.3×10^{-1} persons per reactor-critical-year, respectively. Those values were obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequencies.

5.7.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.7-1a and Figure 5.7-1b display sets of CCDF curves that illustrate the frequencies of exceeding specified numbers of people affected by intermediate-phase relocation within 50 miles and 100 miles, respectively. These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA.

As shown in the figures, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 2×10^3 people for both the 0–50 and 0–100 mile regions. This indicates the likelihood of accidents that require relocating more than 2,000 people within these regions becomes increasingly less likely as the number of relocated people increases.

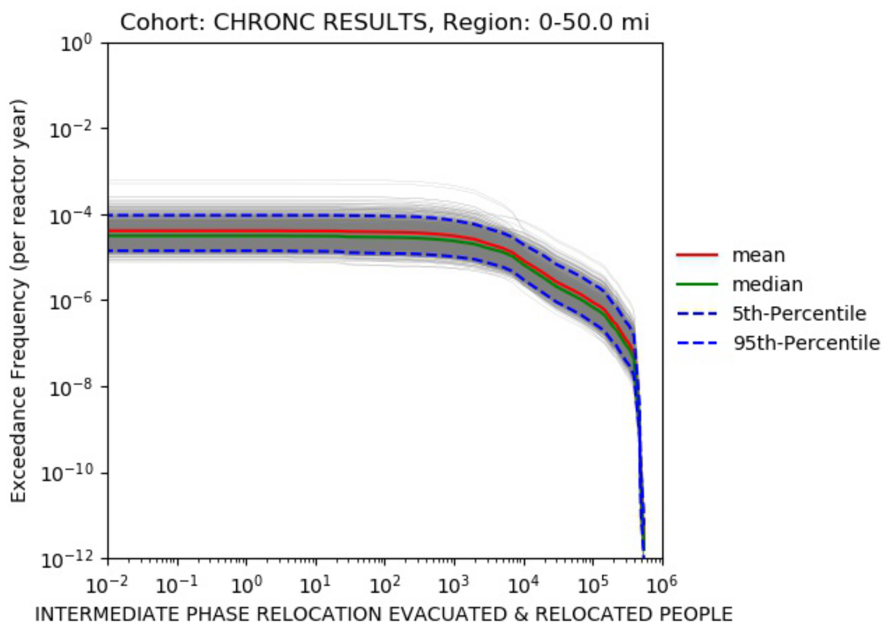

Figure 5.7-1a: CCDF curves for population affected by intermediate-phase relocation (0–50 miles)

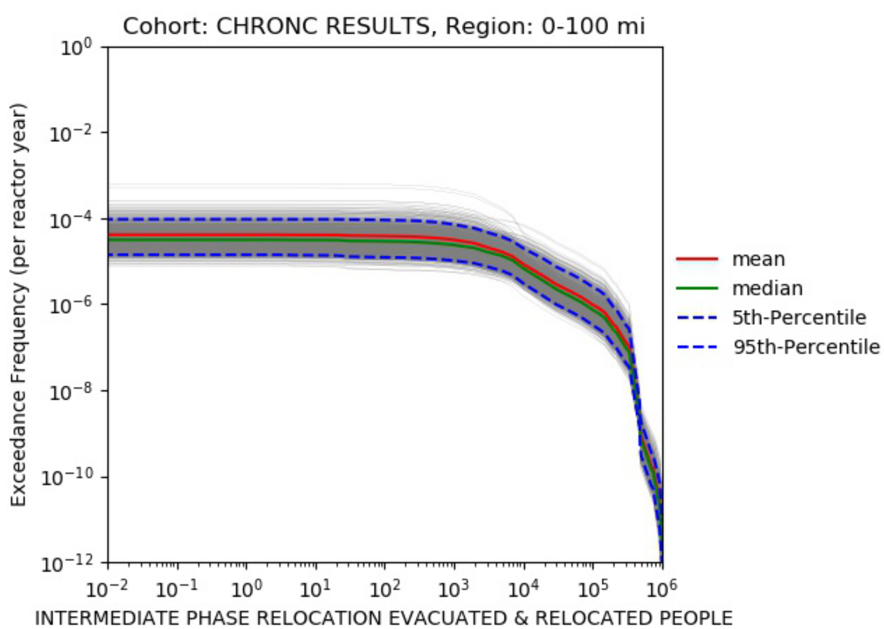

Figure 5.7-1b: CCDF curves for population affected by intermediate-phase relocation (0–100 miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.7-1 and Table 5.7-2 summarize the mean exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding specified numbers of people affected by intermediate-phase relocation within 50 miles and 100 miles, respectively.

Table 5.7-1: Mean and 90% confidence intervals for exceedance frequencies of specified numbers of people affected by intermediate-phase relocation (0–50 miles)

Number of People Affected by Intermediate-Phase Relocation (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1,000	3.1×10^{-5} per reactor-critical-year (1 in 32,000 years)	1.0×10^{-5} – 7.1×10^{-5} per reactor-critical-year (1 in 14,000 to 100,000 years)
10,000	8.4×10^{-6} per reactor-critical-year (1 in 120,000 years)	3.0×10^{-6} – 2.0×10^{-5} per reactor-critical-year (1 in 50,000 to 330,000 years)
100,000	9.0×10^{-7} per reactor-critical-year (1 in 1.1 million years)	3.0×10^{-7} – 2.4×10^{-6} per reactor-critical-year (1 in 420,000 to 3.3 million years)

Table 5.7-2: Mean and 90% confidence intervals for exceedance frequencies of specified numbers of people affected by intermediate-phase relocation (0–100 miles)

Number of People Affected by Intermediate-Phase Relocation (0–100 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
1,000	3.1×10^{-5} per reactor-critical-year (1 in 32,000 years)	1.0×10^{-5} – 7.1×10^{-5} per reactor-critical-year (1 in 14,000 to 100,000 years)
10,000	8.5×10^{-6} per reactor-critical-year (1 in 120,000 years)	3.1×10^{-6} – 2.0×10^{-5} per reactor-critical-year (1 in 50,000 to 320,000 years)
100,000	9.7×10^{-7} per reactor-critical-year (1 in 1 million years)	3.3×10^{-7} – 2.5×10^{-6} per reactor-critical-year (1 in 400,000 to 3 million years)

5.7.2 Significant Contributors to Risk

Figure 4.5-3 and Figure 4.5-4 illustrate the relative contributions of each modeled radiological release category to the mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles, respectively. These figures show that the mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles is mainly dominated by two radiological release categories: (1) an intermediate containment failure release category in which the containment fails hours after vessel breach, due to a global

deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN); and (2) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment are not mitigated significantly by sprays or water pools (LCF). Collectively, these two release categories contribute over 90 percent to the risk from these two metrics.

Table B.7a and Table B.7b in the appendix include the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles, respectively. Virtually all of these basic events are in common for both risk metrics. The most significant contributors to mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles are similar to those seen for other consequence metrics not associated with early health effects. Examples of the most significant contributors include failure of manual extension of TD-AFW during an SBO scenario (contributing approximately 44 percent to these risk measures); many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. As previously noted, some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

Examination of Tables B.7a and B.7b also reveals that SBO sequences contribute approximately 76 percent to mean annual risk of population affected by intermediate-phase relocation within 50 miles and 100 miles. Over half of this contribution comes from CCF of either both RAT input breakers to open or both safeguards load sequencers to operate. Both of these CCFs result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable.

Also as can be seen from Tables B.7a and B.7b, medium LOCAs and loss of NSCW sequences (leading to reactor coolant pump seal LOCAs) contribute approximately another 8 percent and 7 percent, respectively, to these risk metrics. Again, all of these results are consistent with those for other consequence metrics not associated with early health effects.

5.8 Economic Costs

Two offsite public risk metrics pertaining to economic costs are calculated and reported. Risk of total economic costs (0–50 miles, 0–100 miles) measures the total annual risk to society of economic costs from implementation of protective actions to avert radiological dose within 50 miles and 100 miles due to modeled accidental releases of radiological materials from the reference nuclear power plant site.

Economic cost risk provides a measure of the offsite property damage risk attributed to potential accidental releases from nuclear facilities. Similar to population dose, this metric is typically estimated over the 0–50 mile spatial interval to provide input to cost-benefit analyses performed as part of regulatory, backfit, or environmental analyses. Furthermore, economic costs and other socio-economic indicators (e.g., the extent of land contaminated or population affected by protective actions) are also sometimes estimated in PRA studies performed for research purposes to provide additional insights that can be used to either: (1) check for consistency with other correlated results, or (2) evaluate results from a different perspective.

The MACCS code includes economic models for estimating the costs attributed to implementation of modeled protective actions to reduce radiological dose to the offsite public from an assumed accidental release of radiological materials. These costs include: (1) daily costs of compensation for populations subject to evacuation or short-term relocation arising from food, housing, transportation, lost income, or replacement of lost personal property; (2) costs of long-term relocation of populations and businesses in interdicted land areas; (3) depreciation costs that account for loss of value of interdicted property; (4) decontamination costs; and (5) costs arising from implementation of agricultural countermeasures (Chanin et al. 1990; 1998a). However, MACCS does not include models for estimating some cost categories that could be important for potential nuclear accident scenarios. Examples of these cost categories include costs associated with the number of radiation-induced injuries or fatalities and replacement power costs.

In addition to quantifying economic cost risk over the 0–50 mile spatial interval per the regulatory analysis guidelines, this metric is also calculated and reported over the 0–100 mile spatial interval around the reference nuclear power plant site. The basis for this decision was provided in Section 5.3 with the discussion about population dose, and applies to all other offsite public risk metrics that measure risks of societal impacts.

As shown in Table 4-4, the frequency-weighted mean annual risk of total economic costs within 50 miles and 100 miles is $8.0\text{x}10^4$ and $9.6\text{x}10^4$ 2015 U.S. dollars (USD) per reactor-critical-year, respectively. Those values were obtained by weighting the mean (over all weather trials) consequence values for individual release categories by the point estimate of the individual release category frequencies.

5.8.1 CCDF Curves and Summary Tables of Exceedance Frequencies

Figure 5.8-1a and Figure 5.8-1b display sets of CCDF curves that illustrate the frequencies of exceeding specified levels of total economic costs within 50 miles and 100 miles, respectively.

These curves include the contributions from the full spectrum of accident scenarios modeled in the reactor, at-power, internal events and internal floods PRA. As shown in the figures, the slopes of the CCDF curves appear to increase (i.e., become more negative) at about 5×10^{10} 2015 USD for both the 0–50 and 0–100 mile regions. This indicates the likelihood of accidents that results in more than $50 billion 2015 USD in total economic costs within these regions becomes increasingly less likely as the cost increases.

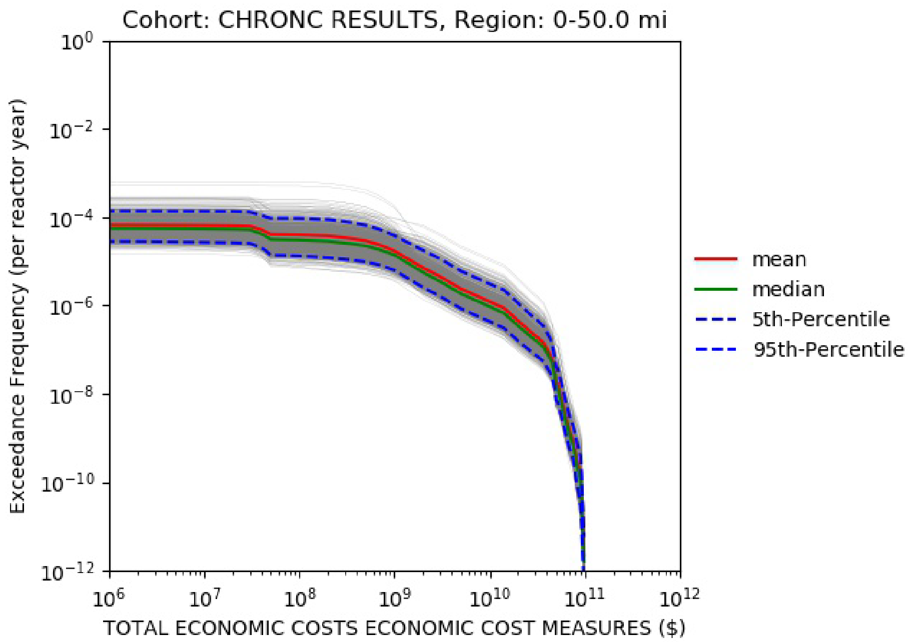

Figure 5.8-1a: CCDF curves for total economic costs (0–50 Miles)

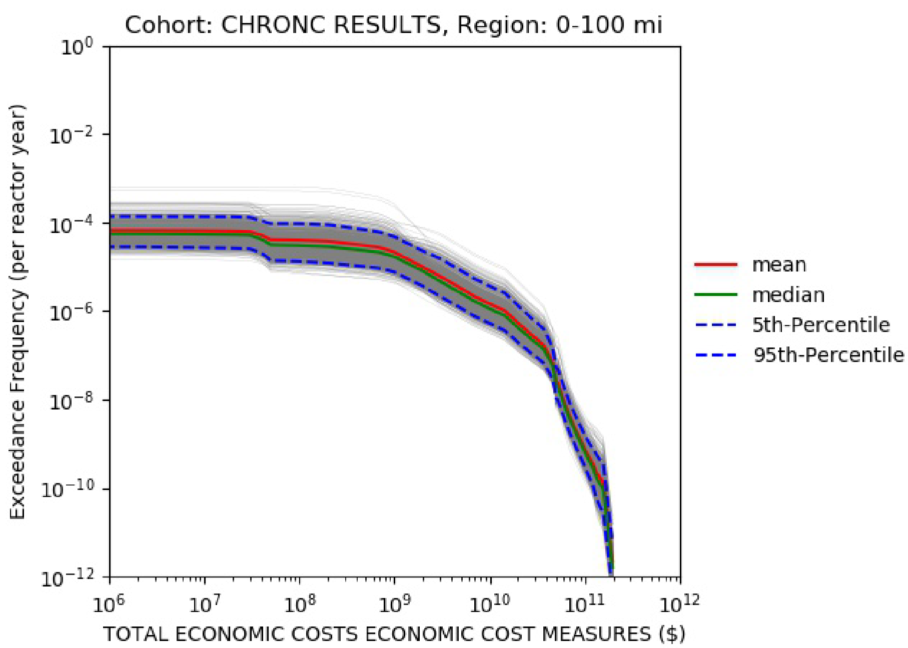

Figure 5.8-1b: CCDF curves for total economic costs (0–100 Miles)

CCDF curves are presented because they are consistent with PRA state-of-practice and were used in the NUREG-1150 summary report. Table 5.8-1 and Table 5.8-2 summarize the mean

exceedance frequencies and the 90 percent probability intervals for the frequencies of exceeding specified levels of total economic costs within 50 miles and 100 miles, respectively.

Table 5.8-1: Mean and 90% confidence intervals for exceedance frequencies of specified levels of total economic costs (0–50 miles)

Total Economic Costs (2015 USD) (0–50 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^8$ (100 million)	$4.0x10^{-5}$ per reactor-critical-year (1 in 25,000 years)	$1.3x10^{-5}$ – $9.3x10^{-5}$ per reactor-critical-year (1 in 11,000 to 77,000 years)
$1x10^9$ (1 billion)	$1.7x10^{-5}$ per reactor-critical-year (1 in 100,000 years)	$6.3x10^{-6}$ – $3.8x10^{-5}$ per reactor-critical-year (1 in 26,000 to 160,000 years)
$1x10^{10}$ (10 billion)	$1.2x10^{-6}$ per reactor-critical-year (1 in 830,000 years)	$4.4x10^{-7}$ – $3.1x10^{-6}$ per reactor-critical-year (1 in 320,000 to 2.3 million years)

Table 5.8-2: Mean and 90% confidence intervals for exceedance frequencies of specified levels of total economic costs (0–100 miles)

Total Economic Costs (2015 USD) (0–100 miles)	Mean Exceedance Frequency	Exceedance Frequency 90% Probability Interval
$1x10^8$ (100 million)	$4.0x10^{-5}$ per reactor-critical-year (1 in 25,000 years)	$1.3x10^{-5}$ – $9.3x10^{-5}$ per reactor-critical-year (1 in 11,000 to 77,000 years)
$1x10^9$ (1 billion)	$2.1x10^{-5}$ per reactor-critical-year (1 in 48,000 years)	$7.6x10^{-6}$ – $4.8x10^{-5}$ per reactor-critical-year (1 in 21,000 to 130,000 years)
$1x10^{10}$ (10 billion)	$1.5x10^{-6}$ per reactor-critical-year (1 in 670,000 years)	$5.3x10^{-7}$ – $3.6x10^{-6}$ per reactor-critical-year (1 in 280,000 to 1.9 million years)

5.8.2 Significant Contributors to Risk

Figure 4.6-3 and Figure 4.6-4 illustrate the relative contributions of each modeled radiological release category to the mean annual risk of total economic costs within 50 miles and 100 miles, respectively. These figures show that mean annual risk of total economic costs within 50 miles and 100 miles are mainly dominated by three radiological release categories: (1) an intermediate containment failure release category in which the containment fails hours after vessel breach, due to a global deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN); (2) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment are not mitigated significantly by sprays or water pools (LCF); and (3) a release category in which a release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage (ISGTR). These are the same three radiological release

categories that dominated mean annual risk of land area within 100 miles exceeding a Cs-137 concentration of 15 Ci/km^2, though the rank order and relative contributions of the radiological release categories are different. Collectively, these three release categories contribute well over 90 percent to the mean annual risk of total economic costs within 50 miles and 100 miles.

Table B.8a and Table B.8b in the appendix include the basic events in the integrated Level 1 and Level 2 PRA logic models that have a composite FV importance measure greater than 0.005 for mean annual risk of total economic costs within 50 miles and 100 miles, respectively. Virtually all of these basic events are in common for both risk metrics. The most significant contributors to mean annual risk of total economic costs within 50 miles or 100 miles are similar to those seen for other consequence metrics not associated with early health effects. Examples of the most significant contributors include failure of manual extension of TD-AFW during an SBO scenario (contributing approximately 44 percent to these risk measures); many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. As previously noted, some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

Examination of Tables B.8a and B.8b also reveals that SBO sequences contribute approximately 77 percent to mean annual risk of total economic costs within 50 miles and 100 miles. Over half of this contribution comes from CCF of either both RAT input breakers to open or both safeguards load sequencers to operate. Both of these CCFs result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable.

Also as can be seen from Tables B.8a and B.8b, loss of NSCW sequences (leading to reactor coolant pump seal LOCAs) and medium LOCAs contribute approximately another 7 percent each to these risk metrics. Again, all of these results are consistent with those for other consequence metrics not associated with early health effects.

5.9 Risk Integration Summary

The main objective of the Risk Integration technical element is to combine the results from the Level 2 radiological release frequency analysis with the corresponding results from the Level 3 offsite radiological consequence analysis to provide an overall characterization of the risk to the offsite public from a broad spectrum of postulated accidents involving a modeled nuclear power plant site. This overall characterization includes a characterization of uncertainty and identification of significant contributors to risk. It is important to note that the uncertainty characterization presented in Section 5 does not include the following sources of uncertainty: (1) epistemic uncertainty arising from imperfect knowledge about the values of some input parameters for phenomena represented in the Level 2 PRA logic model, the Level 2 PRA severe accident progression models, or in the Level 3 PRA offsite radiological consequence models; (2) epistemic uncertainty arising from imperfect knowledge about systems or phenomena modeled in the PRA (model uncertainty); and (3) epistemic uncertainty arising from limitations in the scope of the PRA model (completeness certainty). As previously stated, the SOARCA uncertainty analyses for the Peach Bottom, Surry, and Sequoyah plants involved varying multiple uncertain model parameters in the severe accident progression and offsite radiological consequence models for specific accident scenarios to quantify uncertainty and to determine which parameters have the greatest influence on the results. Insights from these uncertainty analyses offer an additional perspective that can be used to supplement the limited treatment of these sources of uncertainty in the L3PRA project.

Since some results that are traditionally considered products of the Risk Integration technical element were presented in Section 4, Section 5 focuses on documenting methods and results that were not already addressed. However, the following key points from Section 4.7, regarding the L3PRA project results, are worth reiterating here:

- There is an extremely low likelihood of the high doses needed for the induction of early health effects.
- The vast majority of the radiological exposure after a severe accident arises from reoccupation of land, and the number of latent cancer fatalities attributable to this level of radiation exposure are not anticipated to be statistically observable above the expected number of cancer fatalities in the exposed population from all other causes.

The methods and results addressed specifically in Section 5 include:

- Characterizing risk and uncertainty for a selected set of offsite public risk metrics using sets of CCDF curves that reflect both: (1) aleatory uncertainty by considering the full spectrum of modeled accident scenarios and the statistical variability over time in offsite weather conditions, and (2) epistemic uncertainty arising from imperfect knowledge about the values of input parameters in the Level 1 and Level 2 PRA logic models.
- Identifying and characterizing significant contributors to risk stemming from the events, phenomena, or modeling assumptions in the Level 1 and Level 2 PRA logic models,

including: (1) initiating events, (2) random failure events involving SSCs, (3) CCF events involving SSCs, (4) HFEs, and (5) phenomenological modeling assumptions.

Key insights developed from the Risk Integration technical element include:

- There is generally about an order of magnitude in epistemic uncertainty arising from imperfect knowledge about the values of input parameters in the Level 1 and Level 2 PRA logic models. In other words, the points on the 95th and 5th percentile CCDF curves at specified consequence levels generally differ by about a factor of 10.
- Offsite public risk metrics, other than those that relate to early health effects, are generally dominated by the same two or three radiological release categories: (1) a late containment failure release category in which the containment fails tens of hours after the time of vessel breach, due to long-term quasi-static overpressure, and releases to the environment are not mitigated significantly by sprays or water pools (LCF); (2) an intermediate containment failure release category in which the containment fails hours after vessel breach, due to a global deflagration or detonation, and releases to the environment are not mitigated significantly by sprays or water pools (ICF-BURN); and (3) a release category in which a release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage (ISGTR).
- Offsite public risk metrics that relate to early health effects are dominated by four radiological release categories: (1) a release category in which a release occurs from the RCS to the auxiliary building via an ISLOCA, with the break point not submerged and auxiliary building failure (V-F); (2) a release category in which a release occurs from the RCS to the auxiliary building via an ISLOCA, with the break point submerged and auxiliary building failure (V-F-SC); (3) a release category in which a release to the environment occurs via a thermally-induced rupture of one or more steam generator tubes subsequent to the time of core damage (ISGTR); and (4) a release category in which a release from the RCS to the environment occurs via one or more ruptured SG tubes, where the rupture occurred prior to core damage, the release is not mitigated by water above the break point on the secondary side of the affected SG, and one or more secondary-side relief valves are either kept open during the release as a deliberate action or fail in the open position (SGTR-O).
- The accident termination time of 7 days after event initiation is selected for use in the Level 3 analysis. As discussed in Section 2.6.4 of (NRC 2019), this is a longer accident termination time in comparison to past Level 2 PRA studies. This modeling assumption most significantly impacts the LCF release category, as seen in the sensitivity analyses documented in Section 4. The longer accident termination time is appropriate due to the late time of containment failure and the long period of environmental release, as can be seen in the representative source term calculations shown in Figure 2-27 and Figure 2-28 of (NRC 2019). Imposing a shorter accident termination time could result in significantly underestimating the release.
- The Level 2 human reliability approach has deliberately excluded credit for long-term operator actions following core damage during station blackout, which accounts for the

predominant frequency contribution to the most risk-significant release categories. Also, for non-SBO accident scenarios, credit is only given for one attempted operator action before vessel breach and one action after vessel breach. However, it is understood that operators would continue to attempt actions to mitigate the release. This is particularly relevant given the assumption of a long accident termination time. This source of modeling uncertainty is discussed in a sensitivity analysis as part of the Level 2 PRA treatment of uncertainty. The sensitivity analysis considers the impacts of actions to prevent combustion events, control containment pressure, and prevent basemat failure (see Section 4.3.4 in Appendix C of [NRC 2019]).

- Offsite public risk metrics other than those that relate to early health effects generally have a similar set of significant risk contributors, in terms of composite FV importance. Examples of the most significant contributors include failure of manual extension of TD-AFW during an SBO scenario; many events related to combustion (detonations or deflagrations) within containment; and various failures leading to the occurrence of an SBO. Some combustion events result in direct failure of the containment, while others occur early in the accident progression before there is sufficient combustible gas to result in containment failure. In these latter cases, the early combustible events can reduce the amount of combustible gas in containment, thereby significantly reducing the likelihood of a larger combustible event later in the accident progression.

  Other significant risk contributors to offsite public risk metrics other than those that relate to early health effects include:

  - SBO sequences, which generally contribute on the order of 80 percent to each individual risk metric (over half of this contribution comes from CCF of either both RAT input breakers to open or both safeguards load sequencers to operate, both of which result in a non-recoverable loss of all safety-related 4160V AC power, rendering all safety-related equipment unavailable)
  - Loss of NSCW sequences, leading to reactor coolant pump seal LOCAs, which contribute 6-7 percent, depending on the individual risk metric
  - Medium LOCAs, which contribute in the range of 3-8 percent, depending on the individual risk metric

- Offsite public risk metrics that relate to early health effects also have a similar set of significant risk contributors, in terms of composite FV importance. Examples of the most significant contributors include various failures leading to an ISLOCA. ISLOCAs contribute nearly 90 percent to early health effects risk, the vast majority associated with failures of RHR system components. Most of the remaining contribution to these risk metrics (beyond ISLOCAs) comes from SBO sequences that ultimately result in thermally-induced SGTRs.

  The event with the largest individual composite FV importance is the occurrence of an ISLOCA in one of the two RHR system hot leg suction lines, contributing 60 percent to early health effects risk. The event with the next largest composite FV importance is the probability that a large ISLOCA break is not submerged or scrubbed, which results in a much larger source term. This event contributes 56 percent to early health effects risk.

6 MODEL ERRORS AND POTENTIAL CANDIDATES FOR FUTURE WORK

This section provides a list of known model errors and candidates for future work. This list is current as of the time of writing but may be supplemented over the course of the project pending further analyses and ongoing reviews. Table 6.1 provides a list of model known model errors. These errors were not corrected at the time at which they were discovered due to the level of effort needed to correct the error and regenerate all required results. An evaluation of the potential significance of each known error is also included.

Table 6.1: Known modeling errors

Technical Element	Description	Expected Impact	Level of Effort	Notes
RE (Section 3.1.2.6)	After completion of the analysis, it was discovered that the release elevation used in the analysis for MELCOR flow paths FL991 and FL027 were in error. The modeled elevation was 13 m above grade. The corrected physical elevation would be 55 m above grade.	Low for all release categories with the exception of release categories V and LCF-SC.	Low to correct error. High to re-run all analyses and document results	FL027 is a negligible contributor to all release categories except for release category V (STG 5) where it is 10-14% of total and release category LCF-SC (STG 2R2) where it is 20-25% of total. Because these source terms are among the smallest of those analyzed, and because the effect of turbulent wake effects would introduce additional uncertainties in release height regardless of the physical release elevation, this is not expected to be a significant source of error in the overall results.

Table 6.1: Known modeling errors (continued)

Technical Element	Description	Expected Impact	Level of Effort	Notes
RE (Section 3.1.2.6)	After completion of the analysis, it was discovered that the release elevation for MELCOR flow path FL 824 was in error. The modeled elevation was 25 m above grade. The corrected physical elevation would be 16 m above grade.	Low.	Low to correct error. High to re-run all analyses and document results	Releases through normal containment leakage flow paths are typically small in relation to other flow paths. In addition, the effect of turbulent wake effects would introduce additional uncertainties in release height regardless of the physical release elevation.
EC (Section 3.4.2.5)	After development of the input decks for the L3PRA, an error was identified in the derivation of the values for CDNFRM in (Jones, Bixler, and Kimura 2015). Per capita decontamination cost estimates for different land use categories were weighted by land area instead of population.	Low. Preliminary evaluation suggest that correction of this error could result in lowering the per-capita decontamination costs by a factor of less than two for DF3 and approximately 15% for DF5 and DF15.	Medium to develop corrected parameter estimates. Low to correct input decks. High to re-run all analyses and document results	This is not expected to be a significant source of error in overall economic results reported in this project because decontamination costs are typically a small fraction of total economic costs in this analysis. Because the recommendations developed in (Jones, Bixler, and Kimura 2015) remain under review, an updated recommended value is not yet available. Work is ongoing to update this parameter.

The identification of candidates for future work was developed by reviewing the uncertainties and limitations associated with each technical element together with a review of comments from internal reviews and the external peer review. Although all of the candidate sensitivity analyses identified in Section 3 identify candidates for potential future work, some of these are considered to be of higher priority than others. Table 6.2 provides a list of potential candidates for future work that are judged to be of higher priority.

Table 6.2: Potential candidates for future work

Technical Element	Description	Level of Effort	Expected Impact
RE	It is recommended to confirm the adequacy of the process used to select a representative source term for each release category by explicitly modeling all candidate source terms for each release category.	Medium to develop additional input decks. High to re-run all analyses and document results	Low-Medium. For the reasons discussed in (NRC 2019), some of the alternate source terms are not good candidates or are only expected to represent a small portion of the release category frequency. The effect would be most pronounced for the LCF release category, which is characterized by a relatively high frequency and for which there are a number of candidate source terms.
ME	The effect of using different years of weather data (i.e., evaluating inter-annual meteorological variability) has not been explicitly assessed.	Medium to develop weather file for alternate years of data. High to re-run all analyses and document results	Low. Minor changes in most results. Potentially noticeable change for low frequency results characterized by high-dose thresholds (i.e., early injuries or fatalities)
AT	An alternative to the original MACCS Gaussian plume segment model that allows MACCS to use results computed by the NOAA HYSPLIT code (Stein et al. 2015) is under development. It is recommended to examine the impact of this alternate conceptual model once that code development work is completed and accepted.	High for all phases	Not assessed

Table 6.2: Potential candidates for future work (continued)

Technical Element	Description	Level of Effort	Expected Impact
PA	The methodology for developing relocation times remains under development. It is recommended to examine the effect of updated methodologies when that work is completed.	Low to update input decks with revised recommendations. High to re-run all analyses and document results	Low overall. There may be Increased early-phase doses to non-evacuating cohorts with longer relocation times; limited effect overall due to dominance of CHRONC results. Although early health effect estimates are expected to be more sensitive to early phase relocation times, risk numbers are still expected to remain very low because relocation only applies to the non-evacuating cohort, which is a small fraction of the population within 10 miles.
PA	There is uncertainty in the time at which evacuation may be ordered beyond the EPZ. It is believed that there is no current state-of-practice approach for development of MACCS model timings for evacuation beyond the EPZ	Medium-High to independently assess and revise current approach High to re-run all analyses and document results	Low overall. Although there may be an increase in early-phase doses to late evacuating cohorts with more delayed evacuations (or conversely, a decrease in early-phase doses with more rapid evacuation), it is expected that there would be a limited effect overall due to dominance of CHRONC results and because the 10 mile region would not be affected by this modeling approach.
PA	The methodology for developing shielding factors (e.g., GSHFAC, PROTIN, CSFACT) remains under development. It is recommended to examine the effect of updated methodologies when that work is completed.	Low to update input decks with revised recommendations. High to re-run all analyses and document results	Medium. Doses expected to be proportional to shielding factors

Table 6.2: Potential candidates for future work (continued)

Technical Element	Description	Level of Effort	Expected Impact
EC	The effect of the MACCS modeling of the intermediate and recovery phase relocation and habitability decision-making (reflected in MACCS parameters such as DUR_INTPHAS, DPP_INTPHAS, DSCRTI, TMPACT, DSCRLT, and TIMDEC) might significantly affect long term doses and costs, which appear to drive many results.	High to develop alternate parameters and to update input decks. High to re-run all analyses and document results	Medium. Population doses and costs expected to be proportional/inversely proportional to habitability criteria
EC	Examine influence of decontamination plan (levels and unit costs) on dose and cost results	High to develop alternate parameters and to update input decks. High to re-run all analyses and document results	Medium. Increased unit costs expected to increase economic impacts. Very high unit costs may result in increased condemnation of farmland and non-farmland, resulting in higher costs but lower doses
EC	An alternative to the original MACCS economic model that uses input-output methods is under development. It is recommended to examine the impact of this alternate conceptual model once that code development work is completed and accepted.	High for all phases.	Not assessed.
DO*	In contrast to the version of MACCS used to develop the input decks (WinMACCS 3.10), WinMACCS 3.11 introduced the capability to explicitly model all organs identified in FGR-13 cancer risk models. Explicit modeling of all FGR-13 cancer risk organs could confirm the adequacy of the current approach, based on SOARCA precedent for implementing the FGR-13 cancer risk model.	High to develop alternate input decks. High to re-run all analyses and document results.	Low. Total cancer risk results not expected to change significantly. Non-cancer risk metrics should be unaffected.

Table 6.2: Potential candidates for future work (continued)

Technical Element	Description	Level of Effort	Expected Impact
QT	The results of the study are not compared to the results of other studies.	High to identify and evaluate appropriate studies for comparison and to document reasons for differences	n/a
QT/RI	Explicit uncertainty analyses propagating parameter uncertainty distributions for uncertain MACCS parameters, as identified in the SOARCA uncertainty analyses and review of other sources, would provide an indication of the uncertainty in overall risk results arising from uncertain MACCS input parameters.	High for all phases	n/a

**This potential future work would take advantage of the capabilities introduced with WinMACCS 3.11 to explicitly model risks to any organ specified in the DCF file rather than the nine hardwired organs available in WinMACCS 3.10 and earlier.*

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APPENDICES

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1A2	1	820	3.9E+03	1.1E-03	6.6E-01	56000	22100	1.2E-04	2.3E-05	2.5E-07	2.5E-05	2.5E-05	5.9E-07	5.8E-06	1.1E-08	2.7E-10
1A2	2	821	3.2E+03	9.0E-04	6.6E-01	56000	22100	9.5E-05	1.9E-05	2.1E-07	2.1E-05	2.1E-05	4.9E-07	4.8E-06	9.4E-09	2.2E-10
1A2	3	824	1.8E+03	5.1E-04	6.6E-01	56000	22100	5.4E-05	1.1E-05	1.2E-07	1.2E-05	1.2E-05	2.8E-07	2.8E-06	5.3E-09	1.2E-10
1A2	4	820	4.7E+03	1.3E-03	6.0E-01	78100	20300	1.7E-04	2.9E-06	3.9E-07	4.8E-06	4.1E-06	8.7E-08	5.7E-07	4.9E-08	1.2E-09
1A2	5	821	3.9E+03	1.1E-03	6.0E-01	78100	20300	1.4E-04	2.4E-06	3.2E-07	4.0E-06	3.3E-06	7.2E-08	4.7E-07	4.1E-08	9.8E-10
1A2	6	824	2.2E+03	6.3E-04	6.0E-01	78100	20300	7.8E-05	1.4E-06	1.8E-07	2.3E-06	1.9E-06	4.1E-08	2.7E-07	2.3E-08	5.6E-10
1A2	7	820	2.0E+03	5.7E-04	5.7E-01	98400	24000	7.3E-05	1.0E-06	4.5E-08	8.5E-07	3.4E-07	5.0E-09	2.4E-07	2.9E-09	1.0E-10
1A2	8	821	1.6E+03	4.7E-04	5.7E-01	98400	24000	6.0E-05	8.4E-07	3.7E-08	7.0E-07	2.9E-07	4.1E-09	2.0E-07	2.4E-09	8.5E-11
1A2	9	844	4.8E+07	1.5E+01	7.0E-01	100800	5599.9	4.2E-01	5.0E-03	1.6E-04	4.3E-03	1.8E-03	2.8E-05	1.1E-03	1.6E-05	5.4E-07
1A2	10	997	3.0E+06	7.2E-01	1.2E+00	102400	3999.9	1.4E-04	9.3E-07	3.4E-08	8.9E-07	3.8E-07	6.3E-09	2.1E-07	3.6E-09	1.2E-10
1A2	11	998	3.0E+06	7.2E-01	1.2E+00	102400	3999.9	2.3E-04	1.6E-06	5.9E-08	1.5E-06	6.6E-07	1.1E-08	3.6E-07	6.3E-09	2.0E-10
1A2	12	844	2.8E+07	8.2E+00	5.7E-01	106400	3999.9	1.6E-01	3.8E-03	1.0E-04	2.2E-03	7.6E-04	9.0E-06	9.3E-04	5.2E-06	2.3E-07
1A2	13	997	1.5E+06	3.7E-01	1.2E+00	106400	3999.9	3.2E-04	1.9E-06	5.9E-08	1.7E-06	6.6E-07	1.0E-08	4.5E-07	6.0E-09	2.0E-10
1A2	14	998	1.6E+06	3.7E-01	1.2E+00	106400	3999.9	3.4E-04	2.2E-06	6.8E-08	1.9E-06	7.5E-07	1.2E-08	5.2E-07	6.8E-09	2.3E-10
1A2	15	844	2.1E+07	6.4E+00	5.7E-01	110400	4000	1.1E-01	4.4E-03	2.7E-04	2.3E-03	7.1E-04	5.3E-06	1.1E-03	3.2E-06	2.1E-07
1A2	16	997	2.0E+05	4.9E-02	1.2E+00	110400	4000	7.2E-05	3.8E-07	1.1E-08	3.0E-07	1.1E-07	1.7E-09	8.9E-08	1.0E-09	3.5E-11
1A2	17	998	2.8E+05	6.6E-02	1.2E+00	110400	4000	8.5E-05	5.3E-07	1.5E-08	4.1E-07	1.6E-07	2.4E-09	1.2E-07	1.3E-09	4.8E-11
1A2	18	844	1.4E+07	4.3E+00	6.0E-01	114400	4000.1	5.8E-02	2.8E-03	1.7E-04	1.9E-03	5.9E-04	2.4E-06	6.6E-04	1.5E-06	1.5E-07
1A2	19	844	1.0E+07	3.0E+00	6.4E-01	118400	3999.9	3.1E-02	1.4E-03	7.3E-05	1.5E-03	5.0E-04	1.1E-06	2.8E-04	7.0E-07	1.1E-07
1A2	20	844	9.3E+06	2.7E+00	6.5E-01	122400	4000	2.2E-02	1.0E-03	4.7E-05	1.7E-03	6.1E-04	6.6E-07	1.9E-04	4.7E-07	1.0E-07
1A2	21	844	9.0E+06	2.6E+00	6.5E-01	126400	4000	1.9E-02	9.2E-04	3.6E-05	2.2E-03	7.7E-04	4.8E-07	1.6E-04	3.8E-07	1.1E-07
1A2	22	844	8.9E+06	2.6E+00	6.4E-01	130400	4000.1	1.6E-02	8.4E-04	2.9E-05	2.4E-03	9.4E-04	3.5E-07	1.4E-04	3.1E-07	1.1E-07
1A2	23	844	8.7E+06	2.6E+00	6.4E-01	134400	4000	1.4E-02	7.6E-04	2.4E-05	2.3E-03	1.1E-03	2.6E-07	1.2E-04	2.6E-07	1.1E-07
1A2	24	844	8.6E+06	2.5E+00	6.4E-01	138400	4000	1.2E-02	7.1E-04	2.2E-05	2.4E-03	1.0E-03	1.9E-07	1.2E-04	2.2E-07	1.0E-07
1A2	25	844	8.5E+06	2.5E+00	6.4E-01	142400	3999.9	1.1E-02	6.8E-04	2.1E-05	2.6E-03	1.0E-03	1.4E-07	1.1E-04	1.8E-07	1.0E-07
1A2	26	844	8.5E+06	2.5E+00	6.3E-01	146400	4000.1	9.3E-03	6.1E-04	2.1E-05	2.1E-03	1.0E-03	1.1E-07	1.1E-04	1.6E-07	9.8E-08
1A2	27	844	8.4E+06	2.5E+00	6.3E-01	150400	4000	8.2E-03	5.1E-04	2.4E-05	1.7E-03	1.1E-03	7.9E-08	9.3E-05	1.4E-07	9.4E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1A2	28	844	8.3E+06	2.5E+00	6.3E-01	154400	4000	7.3E-03	4.4E-04	3.4E-05	1.4E-03	1.1E-03	5.9E-08	8.5E-05	1.3E-07	9.1E-08
1A2	29	844	8.3E+06	2.4E+00	6.3E-01	158400	4000	6.4E-03	4.0E-04	4.3E-05	1.1E-03	1.2E-03	4.5E-08	8.0E-05	1.2E-07	8.7E-08
1A2	30	844	8.2E+06	2.4E+00	6.3E-01	162400	3999.9	5.7E-03	3.7E-04	5.2E-05	9.4E-04	1.2E-03	3.4E-08	7.7E-05	1.1E-07	8.4E-08
1A2	31	844	8.2E+06	2.4E+00	6.3E-01	166400	4000.1	5.1E-03	3.5E-04	6.0E-05	8.0E-04	1.1E-03	2.6E-08	7.6E-05	9.8E-08	8.2E-08
1A2	32	844	8.2E+06	2.4E+00	6.3E-01	170400	2399.9	2.8E-03	2.0E-04	3.8E-05	4.2E-04	6.4E-04	1.2E-08	4.5E-05	5.6E-08	4.8E-08
1A2	33	844	8.1E+06	2.4E+00	6.3E-01	172800	4000.1	4.3E-03	3.3E-04	5.9E-05	6.2E-04	1.1E-03	1.7E-08	7.6E-05	8.8E-08	7.7E-08
1A2	34	844	8.1E+06	2.4E+00	6.3E-01	176800	4000	3.9E-03	3.2E-04	5.0E-05	5.4E-04	1.1E-03	1.3E-08	7.5E-05	8.3E-08	7.5E-08
1A2	35	844	8.1E+06	2.4E+00	6.3E-01	180800	4000	3.5E-03	3.1E-04	4.3E-05	4.8E-04	1.2E-03	9.7E-09	7.5E-05	7.8E-08	7.2E-08
1A2	36	844	8.1E+06	2.4E+00	6.3E-01	184800	4000	3.2E-03	3.0E-04	3.7E-05	4.2E-04	1.2E-03	7.4E-09	7.4E-05	7.4E-08	7.0E-08
1A2	37	844	8.1E+06	2.4E+00	6.3E-01	188800	3999.9	3.0E-03	3.0E-04	3.4E-05	3.8E-04	1.3E-03	5.7E-09	7.3E-05	7.1E-08	6.7E-08
1A2	38	844	8.0E+06	2.4E+00	6.3E-01	192800	4000.1	2.7E-03	2.9E-04	3.1E-05	3.4E-04	1.4E-03	4.4E-09	7.2E-05	6.8E-08	6.5E-08
1A2	39	844	8.0E+06	2.4E+00	6.3E-01	196800	3999.9	2.5E-03	2.8E-04	2.8E-05	3.1E-04	1.3E-03	3.4E-09	7.0E-05	6.5E-08	6.3E-08
1A2	40	844	7.9E+06	2.3E+00	6.3E-01	200800	4000.1	2.3E-03	2.6E-04	2.3E-05	2.8E-04	1.2E-03	2.6E-09	6.7E-05	6.2E-08	6.0E-08
1A2	41	844	7.9E+06	2.3E+00	6.3E-01	204800	3999.9	2.1E-03	2.5E-04	2.0E-05	2.6E-04	1.2E-03	2.0E-09	6.4E-05	5.9E-08	5.8E-08
1A2	42	844	7.8E+06	2.3E+00	6.3E-01	208800	4000.1	2.0E-03	2.4E-04	1.7E-05	2.4E-04	1.2E-03	1.6E-09	6.2E-05	5.7E-08	5.6E-08
1A2	43	844	7.8E+06	2.3E+00	6.3E-01	212800	3999.9	1.9E-03	2.3E-04	1.6E-05	2.3E-04	1.2E-03	1.2E-09	6.0E-05	5.5E-08	5.5E-08
1A2	44	844	7.8E+06	2.3E+00	6.3E-01	216800	4000.1	1.7E-03	2.2E-04	1.5E-05	2.2E-04	1.2E-03	9.5E-10	5.7E-05	5.4E-08	5.4E-08
1A2	45	844	7.8E+06	2.3E+00	6.3E-01	220800	4000	1.6E-03	2.1E-04	1.4E-05	2.1E-04	1.3E-03	7.5E-10	5.5E-05	5.3E-08	5.3E-08
1A2	46	844	7.8E+06	2.3E+00	6.3E-01	224800	3999.9	1.5E-03	2.0E-04	1.3E-05	2.0E-04	1.4E-03	5.9E-10	5.3E-05	5.2E-08	5.2E-08
1A2	47	844	7.8E+06	2.3E+00	6.3E-01	228800	4000	1.5E-03	2.0E-04	1.1E-05	1.9E-04	1.3E-03	4.6E-10	5.0E-05	5.1E-08	5.1E-08
1A2	48	844	7.8E+06	2.3E+00	6.3E-01	232800	4000	1.4E-03	1.9E-04	9.6E-06	1.8E-04	1.2E-03	3.6E-10	4.8E-05	5.1E-08	5.2E-08
1A2	49	844	7.8E+06	2.3E+00	6.3E-01	236800	4000.1	1.3E-03	1.8E-04	9.1E-06	1.8E-04	1.1E-03	2.8E-10	4.6E-05	5.2E-08	5.3E-08
1A2	50	844	7.7E+06	2.3E+00	6.3E-01	240800	4000	1.2E-03	1.7E-04	8.8E-06	1.7E-04	1.1E-03	2.3E-10	4.5E-05	5.3E-08	5.3E-08
1A2	51	844	7.7E+06	2.3E+00	6.4E-01	244800	3999.9	1.2E-03	1.6E-04	9.0E-06	1.6E-04	1.1E-03	1.9E-10	4.7E-05	5.5E-08	5.5E-08
1A2	52	844	7.8E+06	2.3E+00	6.3E-01	248800	4000.1	1.1E-03	1.5E-04	8.8E-06	1.5E-04	1.1E-03	3.1E-10	4.5E-02	5.4E-08	5.4E-08
1A2	53	844	6.6E+06	1.9E+00	6.7E-01	252800	3999.9	9.7E-04	1.3E-04	6.7E-06	1.4E-04	5.8E-04	1.2E-06	4.0E-02	1.1E-07	3.6E-08
1A2	54	844	5.7E+06	1.6E+00	7.2E-01	256800	4000.1	9.0E-04	7.1E-05	3.7E-06	7.2E-05	2.3E-04	6.5E-07	1.5E-02	5.7E-08	1.9E-08
1A2	55	844	5.6E+06	1.6E+00	7.2E-01	260800	4000	8.8E-04	6.9E-05	4.4E-06	6.8E-05	1.6E-04	5.8E-07	1.0E-02	5.5E-08	2.1E-08
1A2	56	844	5.6E+06	1.5E+00	7.2E-01	264800	3999.9	8.5E-04	6.8E-05	4.6E-06	6.4E-05	1.2E-04	4.8E-07	7.4E-03	4.9E-08	2.2E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1A2	57	844	5.6E+06	1.5E+00	7.3E-01	268800	4000.1	8.2E-04	7.0E-05	5.1E-06	6.4E-05	9.4E-05	4.1E-07	5.5E-03	4.7E-08	2.4E-08
1A2	58	844	5.6E+06	1.5E+00	7.2E-01	272800	4000	7.9E-04	7.3E-05	5.7E-06	6.4E-05	7.3E-05	3.5E-07	4.2E-03	4.6E-08	2.6E-08
1A2	59	844	5.5E+06	1.5E+00	7.3E-01	276800	4000	7.6E-04	9.3E-05	6.0E-06	8.6E-05	8.0E-05	8.9E-07	3.0E-03	7.8E-08	2.7E-08
1A2	60	844	4.9E+06	1.4E+00	7.7E-01	280800	4000	6.9E-04	1.1E-04	5.3E-06	1.1E-04	9.9E-05	1.8E-06	1.7E-03	1.3E-07	2.1E-08
1A2	61	844	4.2E+06	1.1E+00	8.1E-01	284800	3999.9	6.2E-04	6.4E-05	2.8E-06	6.5E-05	5.5E-05	1.1E-06	6.7E-04	7.4E-08	1.1E-08
1A2	62	844	4.2E+06	1.1E+00	8.2E-01	288800	4000	6.1E-04	5.6E-05	3.0E-06	5.5E-05	4.3E-05	8.3E-07	5.2E-04	6.0E-08	1.2E-08
1A2	63	844	4.1E+06	1.1E+00	8.2E-01	292800	4000	5.8E-04	5.3E-05	3.2E-06	5.0E-05	3.5E-05	6.8E-07	4.2E-04	5.2E-08	1.3E-08
1A2	64	844	4.1E+06	1.1E+00	8.3E-01	296800	4000.1	5.7E-04	5.2E-05	3.4E-06	4.8E-05	3.0E-05	5.7E-07	3.5E-04	4.7E-08	1.4E-08
1A2	65	844	4.1E+06	1.1E+00	8.3E-01	300800	3999.9	5.5E-04	4.9E-05	3.5E-06	4.4E-05	2.4E-05	4.6E-07	2.9E-04	4.0E-08	1.4E-08
1A2	66	844	4.0E+06	1.0E+00	8.3E-01	304800	4000.1	5.3E-04	4.8E-05	3.7E-06	4.2E-05	2.0E-05	3.8E-07	2.4E-04	3.6E-08	1.5E-08
1A2	67	844	4.0E+06	1.0E+00	8.3E-01	308800	4000	5.2E-04	4.7E-05	3.8E-06	4.0E-05	1.7E-05	3.1E-07	2.0E-04	3.3E-08	1.5E-08
1A2	68	844	4.0E+06	1.0E+00	8.3E-01	312800	3999.9	5.1E-04	4.7E-05	3.9E-06	4.0E-05	1.5E-05	2.6E-07	1.7E-04	3.1E-08	1.6E-08
1A2	69	844	4.0E+06	1.0E+00	8.4E-01	316800	4000.1	4.9E-04	4.5E-05	3.6E-06	3.8E-05	1.2E-05	2.1E-07	1.4E-04	2.8E-08	1.5E-08
1A2	70	844	4.0E+06	1.0E+00	8.4E-01	320800	4000	4.8E-04	4.2E-05	3.5E-06	3.6E-05	1.0E-05	1.7E-07	1.1E-04	2.5E-08	1.5E-08
1A2	71	844	4.0E+06	1.0E+00	8.4E-01	324800	4000	4.6E-04	4.0E-05	3.8E-06	3.6E-05	9.0E-06	1.5E-07	9.7E-05	2.4E-08	1.6E-08
1A2	72	844	4.0E+06	1.0E+00	8.4E-01	328800	4000	4.5E-04	3.6E-05	5.2E-06	3.4E-05	7.5E-06	1.2E-07	7.9E-05	2.2E-08	1.6E-08
1A2	73	844	4.0E+06	1.0E+00	8.4E-01	332800	4000	4.4E-04	3.5E-05	6.9E-06	3.4E-05	6.7E-06	1.0E-07	6.8E-05	2.2E-08	1.6E-08
1A2	74	844	4.0E+06	1.0E+00	8.4E-01	336800	4000	4.3E-04	3.3E-05	8.0E-06	3.2E-05	5.7E-06	8.2E-08	5.6E-05	2.0E-08	1.6E-08
1A2	75	844	4.0E+06	1.0E+00	8.4E-01	340800	4000	4.2E-04	3.2E-05	9.4E-06	3.3E-05	5.1E-06	7.0E-08	4.8E-05	2.0E-08	1.6E-08
1A2	76	844	4.0E+06	1.0E+00	8.4E-01	344800	4000	4.1E-04	3.0E-05	1.0E-05	3.2E-05	4.5E-06	5.8E-08	4.1E-05	1.9E-08	1.5E-08
1A2	77	844	4.0E+06	1.0E+00	8.4E-01	348800	4000	4.0E-04	2.9E-05	1.1E-05	3.1E-05	4.0E-06	4.7E-08	3.4E-05	1.7E-08	1.5E-08
1A2	78	844	4.0E+06	1.0E+00	8.4E-01	352800	3999.9	3.9E-04	2.8E-05	1.2E-05	3.1E-05	3.6E-06	3.9E-08	2.9E-05	1.7E-08	1.5E-08
1A2	79	844	4.0E+06	1.0E+00	8.4E-01	356800	4000	3.8E-04	2.7E-05	1.3E-05	3.1E-05	3.3E-06	3.4E-08	2.5E-05	1.7E-08	1.5E-08
1A2	80	844	4.0E+06	1.0E+00	8.4E-01	360800	4000.1	3.7E-04	2.6E-05	1.4E-05	3.0E-05	3.0E-06	2.8E-08	2.2E-05	1.6E-08	1.5E-08
1A2	81	844	4.0E+06	1.0E+00	8.4E-01	364800	4000	3.6E-04	2.6E-05	1.5E-05	3.1E-05	2.8E-06	2.4E-08	1.9E-05	1.6E-08	1.5E-08
1A2	82	844	4.0E+06	1.0E+00	8.4E-01	368800	3999.9	3.5E-04	2.6E-05	1.5E-05	3.1E-05	2.7E-06	2.0E-08	1.7E-05	1.6E-08	1.5E-08
1A2	83	844	4.0E+06	1.0E+00	8.4E-01	372800	4000.1	3.4E-04	2.5E-05	1.3E-05	3.1E-05	2.6E-06	1.7E-08	1.5E-05	1.5E-08	1.4E-08
1A2	84	844	3.9E+06	1.0E+00	8.4E-01	376800	3999.9	3.3E-04	2.4E-05	1.1E-05	2.9E-05	2.4E-06	1.4E-08	1.3E-05	1.4E-08	1.4E-08
1A2	85	844	3.9E+06	1.0E+00	8.5E-01	380800	4000	3.2E-04	2.4E-05	9.7E-06	2.9E-05	2.3E-06	1.2E-08	1.2E-05	1.4E-08	1.4E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1A2	86	844	4.0E+06	1.0E+00	8.4E-01	384800	4000.1	3.2E-04	2.4E-05	8.6E-06	2.9E-05	2.3E-06	1.1E-08	1.1E-05	1.4E-08	1.4E-08
1A2	87	844	3.9E+06	1.0E+00	8.4E-01	388800	3999.9	3.1E-04	2.3E-05	7.5E-06	2.9E-05	2.2E-06	9.1E-09	9.8E-06	1.4E-08	1.3E-08
1A2	88	844	3.9E+06	9.9E-01	8.5E-01	392800	4000.1	3.0E-04	2.3E-05	6.7E-06	2.9E-05	2.2E-06	7.8E-09	8.9E-06	1.4E-08	1.3E-08
1A2	89	844	4.0E+06	1.0E+00	8.5E-01	396800	4000	2.9E-04	2.3E-05	6.2E-06	2.9E-05	2.2E-06	7.1E-09	8.6E-06	1.4E-08	1.4E-08
1A2	90	844	3.9E+06	9.9E-01	8.5E-01	400800	3999.9	2.8E-04	2.2E-05	5.4E-06	2.8E-05	2.1E-06	5.9E-09	7.7E-06	1.3E-08	1.3E-08
1A2	91	844	3.9E+06	1.0E+00	8.5E-01	404800	4000	2.8E-04	2.2E-05	5.0E-06	2.9E-05	2.1E-06	5.3E-09	7.3E-06	1.3E-08	1.3E-08
1A2	92	844	3.9E+06	9.8E-01	8.5E-01	408800	4000.1	2.7E-04	2.1E-05	4.4E-06	2.8E-05	2.1E-06	4.6E-09	6.7E-06	1.2E-08	1.2E-08
1A2	93	844	3.9E+06	1.0E+00	8.5E-01	412800	4000	2.6E-04	2.1E-05	4.2E-06	2.8E-05	2.1E-06	4.3E-09	6.6E-06	1.3E-08	1.3E-08
1A2	94	844	3.9E+06	1.0E+00	8.5E-01	416800	3999.9	2.6E-04	2.1E-05	3.8E-06	2.9E-05	2.2E-06	3.7E-09	6.4E-06	1.2E-08	1.2E-08
1A2	95	844	3.9E+06	9.9E-01	8.5E-01	420800	4000	2.5E-04	2.1E-05	3.3E-06	2.8E-05	2.2E-06	3.1E-09	6.0E-06	1.1E-08	1.1E-08
1A2	96	844	3.9E+06	1.0E+00	8.5E-01	424800	4000.1	2.4E-04	2.1E-05	3.0E-06	2.8E-05	2.1E-06	2.6E-09	5.8E-06	1.1E-08	1.1E-08
1A2	97	844	3.9E+06	9.9E-01	8.5E-01	428800	3999.9	2.4E-04	2.0E-05	2.7E-06	2.8E-05	2.2E-06	2.3E-09	5.7E-06	1.0E-08	1.0E-08
1A2	98	844	3.9E+06	9.9E-01	8.5E-01	432800	4000.1	2.3E-04	2.0E-05	2.5E-06	2.8E-05	2.2E-06	2.0E-09	5.5E-06	9.6E-09	9.6E-09
1A2	99	844	3.9E+06	9.8E-01	8.5E-01	436800	4000.1	2.2E-04	1.9E-05	2.3E-06	2.7E-05	2.1E-06	1.8E-09	5.2E-06	9.2E-09	9.3E-09
1A2	100	844	3.9E+06	9.9E-01	8.5E-01	440800	3999.9	2.2E-04	2.0E-05	2.3E-06	2.8E-05	2.2E-06	1.8E-09	5.2E-06	9.7E-09	9.7E-09
1A2	101	844	3.9E+06	9.9E-01	8.5E-01	444800	3999.9	2.1E-04	1.9E-05	2.1E-06	2.8E-05	2.2E-06	1.5E-09	4.9E-06	9.1E-09	9.2E-09
1A2	102	844	3.9E+06	9.9E-01	8.5E-01	448800	4000	2.1E-04	1.8E-05	1.9E-06	2.7E-05	2.2E-06	1.3E-09	4.7E-06	8.7E-09	8.8E-09
1A2	103	844	3.9E+06	9.8E-01	8.5E-01	452800	4000	2.0E-04	1.7E-05	1.8E-06	2.6E-05	2.1E-06	1.2E-09	4.4E-06	8.4E-09	8.5E-09
1A2	104	844	3.9E+06	9.9E-01	8.5E-01	456800	4000.1	2.0E-04	1.8E-05	1.8E-06	2.7E-05	2.2E-06	1.2E-09	4.5E-06	8.7E-09	8.7E-09
1A2	105	844	3.9E+06	9.8E-01	8.5E-01	460800	4000	1.9E-04	1.7E-05	1.7E-06	2.6E-05	2.1E-06	1.1E-09	4.3E-06	8.4E-09	8.4E-09
1A2	106	844	3.9E+06	9.8E-01	8.5E-01	464800	4000	1.9E-04	1.7E-05	1.7E-06	2.6E-05	2.1E-06	1.0E-09	4.3E-06	8.2E-09	8.3E-09
1A2	107	844	3.9E+06	9.9E-01	8.5E-01	468800	4000	1.8E-04	1.7E-05	1.7E-06	2.7E-05	2.1E-06	1.0E-09	4.3E-06	8.3E-09	8.4E-09
1A2	108	844	3.9E+06	9.8E-01	8.5E-01	472800	3999.9	1.8E-04	1.7E-05	1.5E-06	2.6E-05	2.1E-06	8.8E-10	4.3E-06	7.9E-09	8.0E-09
1A2	109	844	3.9E+06	9.9E-01	8.5E-01	476800	4000.1	1.8E-04	1.7E-05	1.5E-06	2.6E-05	2.1E-06	8.0E-10	4.2E-06	7.7E-09	7.8E-09
1A2	110	844	3.9E+06	9.7E-01	8.5E-01	480800	4000	1.7E-04	1.7E-05	1.4E-06	2.6E-05	2.1E-06	7.1E-10	4.2E-06	7.2E-09	7.3E-09
1A2	111	844	3.9E+06	9.8E-01	8.4E-01	484800	4000	1.7E-04	1.7E-05	1.4E-06	2.6E-05	2.2E-06	5.5E-09	4.3E-06	7.6E-09	7.4E-09
1A2	112	844	4.0E+06	9.7E-01	8.2E-01	488800	3999.9	1.7E-04	1.8E-05	1.4E-06	2.6E-05	2.2E-06	1.5E-09	4.4E-06	7.7E-09	7.8E-09
1A2	113	844	4.0E+06	9.7E-01	8.1E-01	492800	4000.1	1.7E-04	1.8E-05	1.5E-06	2.6E-05	2.1E-06	8.7E-10	4.4E-06	7.7E-09	7.8E-09
1A2	114	844	4.0E+06	9.7E-01	8.1E-01	496800	3999.9	1.6E-04	1.8E-05	1.4E-06	2.6E-05	2.1E-06	8.1E-10	4.4E-06	7.7E-09	7.8E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1A2	115	844	3.9E+06	9.6E-01	8.1E-01	500800	3200	1.3E-04	1.4E-05	1.1E-06	2.0E-05	1.7E-06	6.0E-10	3.5E-06	5.9E-09	6.0E-09
1A2_TR28	1	820	3.9E+03	1.1E-03	6.6E-01	56000	22100	1.2E-04	2.3E-05	2.5E-07	2.5E-05	2.5E-05	5.9E-07	5.8E-06	1.1E-08	2.7E-10
1A2_TR28	2	821	3.2E+03	9.0E-04	6.6E-01	56000	22100	9.5E-05	1.9E-05	2.1E-07	2.1E-05	2.1E-05	4.9E-07	4.8E-06	9.4E-09	2.2E-10
1A2_TR28	3	824	1.8E+03	5.1E-04	6.6E-01	56000	22100	5.4E-05	1.1E-05	1.2E-07	1.2E-05	1.2E-05	2.8E-07	2.8E-06	5.3E-09	1.2E-10
1A2_TR28	4	820	4.7E+03	1.3E-03	6.0E-01	78100	20300	1.7E-04	2.9E-06	3.9E-07	4.8E-06	4.1E-06	8.7E-08	5.7E-07	4.9E-08	1.2E-09
1A2_TR28	5	821	3.9E+03	1.1E-03	6.0E-01	78100	20300	1.4E-04	2.4E-06	3.2E-07	4.0E-06	3.3E-06	7.2E-08	4.7E-07	4.1E-08	9.8E-10
1A2_TR28	6	824	2.2E+03	6.3E-04	6.0E-01	78100	20300	7.8E-05	1.4E-06	1.8E-07	2.3E-06	1.9E-06	4.1E-08	2.7E-07	2.3E-08	5.6E-10
1B	1	820	4.4E+03	1.2E-03	6.5E-01	13000	22000	1.3E-04	1.9E-05	3.8E-07	2.3E-05	2.1E-05	2.7E-07	4.1E-06	1.2E-08	2.4E-10
1B	2	821	3.6E+03	1.0E-03	6.5E-01	13000	22000	1.1E-04	1.6E-05	3.2E-07	1.9E-05	1.7E-05	2.2E-07	3.4E-06	9.9E-09	2.0E-10
1B	3	824	2.1E+03	5.8E-04	6.5E-01	13000	22000	6.0E-05	8.9E-06	1.8E-07	1.1E-05	9.9E-06	1.3E-07	1.9E-06	5.6E-09	1.1E-10
1B	4	820	5.4E+03	1.5E-03	5.8E-01	35000	21000	1.8E-04	2.6E-06	1.1E-07	4.9E-06	2.9E-06	2.3E-08	3.9E-07	3.9E-09	1.3E-10
1B	5	821	4.5E+03	1.3E-03	5.8E-01	35000	21000	1.5E-04	2.1E-06	9.0E-08	4.0E-06	2.4E-06	1.9E-08	3.2E-07	3.2E-09	1.1E-10
1B	6	824	2.6E+03	7.2E-04	5.8E-01	35000	21000	8.4E-05	1.2E-06	5.2E-08	2.3E-06	1.4E-06	1.1E-08	1.8E-07	1.8E-09	6.2E-11
1B	7	820	6.4E+03	1.8E-03	5.4E-01	56000	22000	2.0E-04	7.9E-07	1.6E-08	2.9E-06	1.2E-06	2.5E-09	6.0E-08	4.9E-10	7.6E-11
1B	8	821	5.3E+03	1.5E-03	5.4E-01	56000	22000	1.6E-04	6.5E-07	1.3E-08	2.4E-06	9.7E-07	2.0E-09	4.9E-08	4.1E-10	6.3E-11
1B	9	824	3.0E+03	8.7E-04	5.4E-01	56000	22000	9.4E-05	3.7E-07	7.3E-09	1.4E-06	5.6E-07	1.2E-09	2.8E-08	2.3E-10	3.6E-11
1B	10	820	7.4E+03	2.2E-03	5.2E-01	78000	20400	1.9E-04	5.2E-07	9.2E-09	2.3E-06	1.0E-06	8.8E-10	3.2E-08	2.1E-10	6.6E-11
1B	11	821	6.2E+03	1.8E-03	5.2E-01	78000	20400	1.6E-04	4.3E-07	7.6E-09	1.9E-06	8.6E-07	7.3E-10	2.6E-08	1.8E-10	5.5E-11
1B	12	820	8.5E+03	2.5E-03	5.0E-01	98400	24000	2.3E-04	4.4E-07	1.1E-08	2.1E-06	1.3E-06	5.0E-10	2.3E-08	1.6E-10	7.3E-11
1B	13	821	7.0E+03	2.1E-03	5.0E-01	98400	24000	1.9E-04	3.6E-07	8.9E-09	1.8E-06	1.1E-06	4.1E-10	1.9E-08	1.3E-10	6.0E-11
1B	14	824	4.0E+03	1.2E-03	5.0E-01	98400	24000	1.1E-04	2.1E-07	5.1E-09	1.0E-06	6.4E-07	2.4E-10	1.1E-08	7.3E-11	3.4E-11
1B	15	820	9.5E+03	2.8E-03	4.8E-01	122400	20000	2.0E-04	2.8E-07	9.7E-09	1.3E-06	1.3E-06	2.4E-10	1.2E-08	9.5E-11	5.8E-11
1B	16	821	7.9E+03	2.3E-03	4.8E-01	122400	20000	1.6E-04	2.3E-07	8.0E-09	1.1E-06	1.1E-06	1.9E-10	1.0E-08	7.9E-11	4.8E-11
1B	17	824	4.5E+03	1.3E-03	4.8E-01	122400	20000	9.3E-05	1.3E-07	4.6E-09	6.1E-07	6.2E-07	1.1E-10	5.8E-09	4.5E-11	2.7E-11
1B	18	820	1.0E+04	3.1E-03	4.7E-01	142400	20000	2.0E-04	2.2E-07	1.0E-08	1.0E-06	1.6E-06	1.5E-10	8.2E-09	7.8E-11	5.4E-11
1B	19	821	8.6E+03	2.6E-03	4.7E-01	142400	20000	1.7E-04	1.8E-07	8.6E-09	8.4E-07	1.3E-06	1.3E-10	6.8E-09	6.4E-11	4.5E-11
1B	20	824	4.9E+03	1.5E-03	4.7E-01	142400	20000	9.5E-05	1.0E-07	4.9E-09	4.8E-07	7.4E-07	7.2E-11	3.9E-09	3.7E-11	2.6E-11
1B	21	820	1.1E+04	3.4E-03	4.6E-01	162400	22400	2.3E-04	2.0E-07	1.3E-08	9.3E-07	2.5E-06	1.1E-10	6.2E-09	7.2E-11	5.7E-11
1B	22	821	9.3E+03	2.8E-03	4.6E-01	162400	22400	1.9E-04	1.7E-07	1.1E-08	7.7E-07	2.1E-06	9.2E-11	5.1E-09	6.0E-11	4.7E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	23	824	5.3E+03	1.6E-03	4.6E-01	162400	22400	1.1E-04	9.6E-08	6.3E-09	4.4E-07	1.2E-06	5.3E-11	2.9E-09	3.4E-11	2.7E-11
1B	24	844	6.7E+06	1.9E+00	9.1E-01	172800	3999.8	1.2E-02	8.3E-06	5.7E-07	3.9E-05	1.1E-04	4.4E-09	2.4E-07	3.0E-09	2.4E-09
1B	25	844	7.2E+06	2.0E+00	7.1E-01	176800	4000.2	1.7E-02	1.2E-05	9.2E-07	5.6E-05	1.8E-04	6.2E-09	3.5E-07	4.4E-09	3.5E-09
1B	26	844	7.5E+06	2.0E+00	6.9E-01	180800	3999.9	1.7E-02	1.3E-05	1.2E-06	6.1E-05	2.5E-04	6.6E-09	4.1E-07	4.9E-09	4.0E-09
1B	27	820	1.1E+04	3.4E-03	4.5E-01	184800	24000	2.2E-04	1.4E-07	1.9E-08	5.7E-07	8.4E-06	5.5E-11	4.8E-05	5.1E-11	4.5E-11
1B	28	821	9.3E+03	2.8E-03	4.5E-01	184800	24000	1.8E-04	1.2E-07	1.6E-08	4.7E-07	7.0E-06	4.5E-11	4.0E-05	4.2E-11	3.7E-11
1B	29	824	5.3E+03	1.6E-03	4.5E-01	184800	24000	1.0E-04	6.8E-08	9.2E-09	2.7E-07	4.0E-06	2.6E-11	2.3E-05	2.4E-11	2.1E-11
1B	30	844	8.0E+06	2.2E+00	6.7E-01	184800	3999.9	1.7E-02	1.3E-05	1.3E-06	6.0E-05	3.1E-04	6.2E-09	5.5E-07	4.9E-09	4.1E-09
1B	31	844	8.3E+06	2.3E+00	6.6E-01	188800	4000.2	1.7E-02	1.3E-05	1.5E-06	5.7E-05	4.7E-04	5.7E-09	1.3E-06	4.9E-09	4.1E-09
1B	32	844	9.0E+06	2.6E+00	6.5E-01	192800	3999.8	1.8E-02	1.1E-05	1.6E-06	4.9E-05	1.1E-03	4.6E-09	9.9E-03	4.3E-09	3.7E-09
1B	33	844	9.3E+06	2.7E+00	6.4E-01	196800	4000.2	1.9E-02	9.1E-06	1.5E-06	3.3E-05	9.0E-04	2.9E-09	6.1E-03	3.2E-09	2.8E-09
1B	34	844	9.4E+06	2.7E+00	6.4E-01	200800	3999.9	1.8E-02	8.3E-06	1.5E-06	2.4E-05	6.5E-04	1.9E-09	4.0E-03	2.5E-09	2.3E-09
1B	35	844	9.4E+06	2.7E+00	6.4E-01	204800	3999.9	1.8E-02	8.5E-06	1.6E-06	2.0E-05	5.0E-04	1.4E-09	2.8E-03	2.3E-09	2.1E-09
1B	36	820	1.1E+04	3.4E-03	4.5E-01	208800	20000	1.6E-04	1.4E-07	2.1E-08	2.0E-07	3.2E-06	4.0E-10	1.7E-05	4.4E-11	2.4E-11
1B	37	821	9.1E+03	2.8E-03	4.5E-01	208800	20000	1.4E-04	1.2E-07	1.7E-08	1.6E-07	2.7E-06	3.3E-10	1.4E-05	3.7E-11	2.0E-11
1B	38	824	5.2E+03	1.6E-03	4.5E-01	208800	20000	7.8E-05	6.6E-08	9.7E-09	9.2E-08	1.5E-06	1.9E-10	7.9E-06	2.1E-11	1.1E-11
1B	39	844	9.4E+06	2.7E+00	6.4E-01	208800	4000.2	1.8E-02	9.3E-06	1.7E-06	1.7E-05	4.0E-04	1.1E-09	2.2E-03	2.2E-09	2.1E-09
1B	40	844	9.4E+06	2.7E+00	6.4E-01	212800	3999.8	1.7E-02	1.0E-05	1.8E-06	1.6E-05	3.3E-04	9.2E-10	1.7E-03	2.2E-09	2.2E-09
1B	41	844	9.4E+06	2.7E+00	6.4E-01	216800	3999.9	1.7E-02	1.2E-05	2.0E-06	1.5E-05	2.8E-04	7.9E-10	1.4E-03	2.3E-09	2.3E-09
1B	42	844	9.3E+06	2.7E+00	6.4E-01	220800	4000.1	1.7E-02	1.8E-05	2.2E-06	2.2E-05	2.3E-04	8.9E-08	1.1E-03	7.1E-09	2.4E-09
1B	43	844	9.3E+06	2.7E+00	6.4E-01	224800	3999.9	1.6E-02	2.1E-05	2.2E-06	2.5E-05	1.9E-04	1.3E-07	9.1E-04	9.1E-09	2.4E-09
1B	44	820	1.1E+04	3.3E-03	4.4E-01	228800	20000	1.5E-04	2.5E-07	2.8E-08	2.3E-07	1.5E-06	9.7E-10	6.7E-06	8.1E-11	3.0E-11
1B	45	821	8.7E+03	2.7E-03	4.4E-01	228800	20000	1.2E-04	2.1E-07	2.3E-08	1.9E-07	1.2E-06	8.0E-10	5.6E-06	6.7E-11	2.4E-11
1B	46	844	9.3E+06	2.7E+00	6.4E-01	228800	4000.3	1.6E-02	2.2E-05	2.4E-06	2.3E-05	1.7E-04	1.1E-07	7.9E-04	8.3E-09	2.5E-09
1B	47	844	9.2E+06	2.7E+00	6.4E-01	232800	4000	1.6E-02	2.3E-05	2.6E-06	2.3E-05	1.5E-04	1.0E-07	6.9E-04	7.9E-09	2.7E-09
1B	48	844	9.1E+06	2.6E+00	6.4E-01	236800	3999.7	1.5E-02	2.5E-05	2.8E-06	2.2E-05	1.3E-04	8.9E-08	6.1E-04	7.6E-09	2.9E-09
1B	49	844	9.1E+06	2.6E+00	6.4E-01	240800	4000.1	1.5E-02	2.6E-05	3.0E-06	2.2E-05	1.2E-04	8.0E-08	5.5E-04	7.4E-09	3.1E-09
1B	50	844	9.0E+06	2.6E+00	6.4E-01	244800	4000.2	1.5E-02	2.8E-05	3.2E-06	2.1E-05	1.1E-04	7.3E-08	4.9E-04	7.2E-09	3.3E-09
1B	51	820	1.0E+04	3.1E-03	4.4E-01	248800	24000	1.6E-04	4.5E-07	4.4E-08	3.1E-07	1.0E-06	1.2E-09	4.5E-06	1.1E-10	4.7E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	52	821	8.2E+03	2.5E-03	4.4E-01	248800	24000	1.3E-04	3.7E-07	3.6E-08	2.5E-07	8.6E-07	1.0E-09	3.7E-06	9.1E-11	3.8E-11
1B	53	844	9.0E+06	2.6E+00	6.4E-01	248800	3999.8	1.4E-02	3.0E-05	3.3E-06	2.1E-05	9.9E-05	6.7E-08	4.5E-04	7.1E-09	3.5E-09
1B	54	844	8.9E+06	2.6E+00	6.4E-01	252800	4000.1	1.4E-02	3.2E-05	3.5E-06	2.1E-05	9.0E-05	6.1E-08	4.1E-04	7.1E-09	3.7E-09
1B	55	844	9.0E+06	2.5E+00	6.2E-01	256800	3999.9	1.4E-02	3.4E-05	3.7E-06	2.1E-05	8.4E-05	5.8E-08	3.8E-04	7.1E-09	3.9E-09
1B	56	844	8.9E+06	2.5E+00	6.0E-01	260800	4000	1.4E-02	3.7E-05	3.8E-06	2.2E-05	7.8E-05	6.1E-08	3.5E-04	7.4E-09	4.1E-09
1B	57	844	8.8E+06	2.5E+00	5.9E-01	264800	4000.2	1.3E-02	4.3E-05	3.9E-06	2.9E-05	7.5E-05	1.3E-07	3.1E-04	1.1E-08	4.1E-09
1B	58	844	8.8E+06	2.5E+00	5.9E-01	268800	3999.9	1.3E-02	5.3E-05	3.7E-06	4.4E-05	7.8E-05	2.8E-07	2.6E-04	1.7E-08	3.9E-09
1B	59	820	9.2E+03	2.8E-03	4.3E-01	272800	20000	1.2E-04	5.9E-07	3.8E-08	4.5E-07	6.7E-07	2.9E-09	2.1E-06	1.8E-10	4.1E-11
1B	60	821	7.6E+03	2.3E-03	4.3E-01	272800	20000	9.7E-05	4.9E-07	3.1E-08	3.7E-07	5.5E-07	2.4E-09	1.7E-06	1.5E-10	3.4E-11
1B	61	824	4.4E+03	1.3E-03	4.3E-01	272800	20000	5.5E-05	2.8E-07	1.8E-08	2.1E-07	3.2E-07	1.4E-09	9.7E-07	8.5E-11	1.9E-11
1B	62	844	8.7E+06	2.4E+00	5.9E-01	272800	4000.1	1.3E-02	5.5E-05	3.8E-06	4.4E-05	7.3E-05	2.7E-07	2.4E-04	1.7E-08	4.0E-09
1B	63	844	8.6E+06	2.4E+00	5.9E-01	276800	3999.9	1.2E-02	6.1E-05	3.7E-06	5.1E-05	7.4E-05	3.4E-07	2.2E-04	2.0E-08	3.9E-09
1B	64	844	8.6E+06	2.4E+00	5.9E-01	280800	4000.2	1.2E-02	6.1E-05	3.8E-06	4.7E-05	6.7E-05	3.0E-07	2.0E-04	1.9E-08	4.1E-09
1B	65	844	8.5E+06	2.4E+00	5.9E-01	284800	4000	1.2E-02	6.2E-05	3.9E-06	4.4E-05	6.1E-05	2.8E-07	1.8E-04	1.8E-08	4.3E-09
1B	66	844	8.4E+06	2.3E+00	5.9E-01	288800	4000.1	1.2E-02	6.3E-05	4.0E-06	4.2E-05	5.7E-05	2.6E-07	1.7E-04	1.7E-08	4.5E-09
1B	67	820	8.4E+03	2.6E-03	4.3E-01	292800	24000	1.3E-04	8.2E-07	4.8E-08	4.3E-07	5.2E-07	2.3E-09	1.6E-06	1.7E-10	5.6E-11
1B	68	821	6.9E+03	2.1E-03	4.3E-01	292800	24000	1.0E-04	6.8E-07	4.0E-08	3.6E-07	4.3E-07	1.9E-09	1.3E-06	1.4E-10	4.7E-11
1B	69	824	4.0E+03	1.2E-03	4.3E-01	292800	24000	5.9E-05	3.9E-07	2.3E-08	2.0E-07	2.4E-07	1.1E-09	7.6E-07	8.1E-11	2.7E-11
1B	70	844	8.3E+06	2.3E+00	6.0E-01	292800	3999.9	1.2E-02	6.5E-05	4.1E-06	4.0E-05	5.2E-05	2.4E-07	1.6E-04	1.6E-08	4.6E-09
1B	71	844	8.3E+06	2.3E+00	6.0E-01	296800	4000	1.1E-02	6.7E-05	4.1E-06	3.8E-05	4.8E-05	2.2E-07	1.5E-04	1.5E-08	4.7E-09
1B	72	844	8.2E+06	2.3E+00	6.0E-01	300800	4000	1.1E-02	6.9E-05	4.1E-06	3.7E-05	4.4E-05	2.0E-07	1.4E-04	1.5E-08	4.8E-09
1B	73	844	8.1E+06	2.2E+00	6.0E-01	304800	4000	1.1E-02	7.1E-05	4.1E-06	3.5E-05	4.1E-05	1.8E-07	1.3E-04	1.4E-08	4.9E-09
1B	74	844	8.1E+06	2.2E+00	6.0E-01	308800	4000	1.1E-02	7.4E-05	4.2E-06	3.4E-05	3.8E-05	1.7E-07	1.2E-04	1.3E-08	5.0E-09
1B	75	844	8.0E+06	2.2E+00	6.0E-01	312800	4000	1.0E-02	7.6E-05	4.1E-06	3.3E-05	3.5E-05	1.6E-07	1.1E-04	1.3E-08	5.0E-09
1B	76	820	7.6E+03	2.3E-03	4.2E-01	316800	20000	9.3E-05	8.2E-07	4.0E-08	3.0E-07	2.7E-07	1.2E-09	9.2E-07	1.1E-10	5.1E-11
1B	77	821	6.3E+03	1.9E-03	4.2E-01	316800	20000	7.6E-05	6.8E-07	3.3E-08	2.5E-07	2.2E-07	1.0E-09	7.6E-07	9.3E-11	4.2E-11
1B	78	844	7.9E+06	2.2E+00	6.0E-01	316800	4000	1.0E-02	7.9E-05	4.2E-06	3.2E-05	3.2E-05	1.4E-07	1.0E-04	1.2E-08	5.2E-09
1B	79	844	7.9E+06	2.2E+00	6.0E-01	320800	4000	1.0E-02	8.2E-05	4.1E-06	3.1E-05	2.9E-05	1.3E-07	9.8E-05	1.2E-08	5.2E-09
1B	80	844	7.8E+06	2.1E+00	6.0E-01	324800	4000	9.8E-03	8.5E-05	4.1E-06	3.0E-05	2.7E-05	1.2E-07	9.3E-05	1.1E-08	5.3E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	81	844	7.7E+06	2.1E+00	6.0E-01	328800	4000	9.6E-03	8.9E-05	4.1E-06	3.0E-05	2.5E-05	1.1E-07	8.7E-05	1.1E-08	5.4E-09
1B	82	844	7.7E+06	2.1E+00	6.0E-01	332800	4000	9.4E-03	9.2E-05	4.0E-06	2.9E-05	2.3E-05	1.0E-07	8.3E-05	1.1E-08	5.3E-09
1B	83	820	6.9E+03	2.1E-03	4.2E-01	336800	20000	8.3E-05	1.0E-06	3.7E-08	2.8E-07	1.8E-07	8.1E-10	7.1E-07	9.3E-11	5.3E-11
1B	84	821	5.7E+03	1.7E-03	4.2E-01	336800	20000	6.8E-05	8.2E-07	3.1E-08	2.3E-07	1.5E-07	6.7E-10	5.8E-07	7.7E-11	4.3E-11
1B	85	844	7.6E+06	2.1E+00	6.0E-01	336800	4000	9.2E-03	9.6E-05	3.8E-06	2.9E-05	2.1E-05	9.5E-08	7.9E-05	1.0E-08	5.2E-09
1B	86	844	7.6E+06	2.1E+00	6.0E-01	340800	4000	9.0E-03	1.0E-04	3.8E-06	2.9E-05	2.0E-05	8.8E-08	7.5E-05	9.8E-09	5.4E-09
1B	87	844	7.5E+06	2.0E+00	6.0E-01	344800	4000	8.8E-03	1.0E-04	3.9E-06	2.8E-05	1.8E-05	8.1E-08	7.2E-05	9.6E-09	5.5E-09
1B	88	844	7.4E+06	2.0E+00	6.1E-01	348800	4000	8.6E-03	1.1E-04	3.8E-06	2.8E-05	1.7E-05	7.5E-08	6.9E-05	9.3E-09	5.5E-09
1B	89	844	7.4E+06	2.0E+00	6.1E-01	352800	4000	8.4E-03	1.1E-04	3.8E-06	2.8E-05	1.5E-05	6.9E-08	6.6E-05	9.1E-09	5.6E-09
1B	90	820	6.2E+03	1.9E-03	4.1E-01	356800	24000	8.8E-05	1.5E-06	4.2E-08	3.4E-07	1.4E-07	6.2E-10	7.0E-07	9.8E-11	6.7E-11
1B	91	821	5.2E+03	1.6E-03	4.1E-01	356800	24000	7.2E-05	1.2E-06	3.5E-08	2.8E-07	1.1E-07	5.1E-10	5.8E-07	8.1E-11	5.5E-11
1B	92	844	7.3E+06	2.0E+00	6.1E-01	356800	3999.8	8.3E-03	1.2E-04	3.8E-06	2.8E-05	1.4E-05	6.4E-08	6.4E-05	8.9E-09	5.7E-09
1B	93	844	7.3E+06	2.0E+00	6.1E-01	360800	4000.1	8.1E-03	1.2E-04	3.7E-06	2.9E-05	1.3E-05	5.9E-08	6.3E-05	8.7E-09	5.7E-09
1B	94	844	7.2E+06	1.9E+00	6.1E-01	364800	3999.7	7.9E-03	1.3E-04	3.6E-06	2.9E-05	1.2E-05	5.4E-08	6.1E-05	8.5E-09	5.8E-09
1B	95	844	7.2E+06	1.9E+00	6.1E-01	368800	4000.3	7.8E-03	1.3E-04	3.5E-06	3.0E-05	1.1E-05	5.0E-08	6.0E-05	8.3E-09	5.8E-09
1B	96	844	7.1E+06	1.9E+00	6.1E-01	372800	3999.8	7.6E-03	1.4E-04	3.5E-06	3.1E-05	1.0E-05	4.6E-08	5.9E-05	8.1E-09	5.8E-09
1B	97	844	7.0E+06	1.9E+00	6.1E-01	376800	3999.9	7.4E-03	1.5E-04	3.5E-06	3.2E-05	9.3E-06	4.3E-08	5.8E-05	8.1E-09	6.0E-09
1B	98	820	5.6E+03	1.7E-03	4.1E-01	380800	20000	6.4E-05	1.6E-06	3.0E-08	3.6E-07	7.0E-08	3.3E-10	5.4E-07	7.2E-11	5.6E-11
1B	99	821	4.7E+03	1.4E-03	4.1E-01	380800	20000	5.3E-05	1.3E-06	2.5E-08	3.0E-07	5.8E-08	2.7E-10	4.5E-07	5.9E-11	4.6E-11
1B	100	844	7.0E+06	1.9E+00	6.1E-01	380800	4000.2	7.3E-03	1.5E-04	3.4E-06	3.4E-05	8.5E-06	4.0E-08	5.7E-05	7.9E-09	6.0E-09
1B	101	844	6.9E+06	1.9E+00	6.1E-01	384800	4000	7.1E-03	1.6E-04	3.3E-06	3.6E-05	7.7E-06	3.7E-08	5.7E-05	7.8E-09	6.0E-09
1B	102	844	6.9E+06	1.8E+00	6.2E-01	388800	4000.1	7.0E-03	1.6E-04	3.2E-06	3.9E-05	7.1E-06	3.4E-08	5.7E-05	7.5E-09	5.9E-09
1B	103	844	6.8E+06	1.8E+00	6.2E-01	392800	3999.8	6.8E-03	1.7E-04	3.0E-06	4.1E-05	6.6E-06	3.1E-08	5.7E-05	7.3E-09	5.9E-09
1B	104	844	6.8E+06	1.8E+00	6.2E-01	396800	4000.1	6.7E-03	1.8E-04	2.9E-06	4.4E-05	6.2E-06	2.9E-08	5.7E-05	7.2E-09	5.8E-09
1B	105	820	5.1E+03	1.5E-03	4.0E-01	400800	24000	6.8E-05	2.2E-06	3.1E-08	6.2E-07	6.4E-08	2.6E-10	6.5E-07	7.8E-11	6.8E-11
1B	106	821	4.2E+03	1.3E-03	4.0E-01	400800	24000	5.6E-05	1.8E-06	2.5E-08	5.1E-07	5.3E-08	2.1E-10	5.4E-07	6.5E-11	5.6E-11
1B	107	824	2.4E+03	7.2E-04	4.0E-01	400800	24000	3.2E-05	1.1E-06	1.5E-08	2.9E-07	3.0E-08	1.2E-10	3.1E-07	3.7E-11	3.2E-11
1B	108	844	6.7E+06	1.8E+00	6.2E-01	400800	3999.9	6.5E-03	1.9E-04	2.9E-06	4.7E-05	6.0E-06	2.7E-08	5.7E-05	7.2E-09	6.0E-09
1B	109	844	6.7E+06	1.8E+00	6.2E-01	404800	4000.2	6.4E-03	1.9E-04	2.8E-06	5.0E-05	5.8E-06	2.5E-08	5.7E-05	7.0E-09	6.0E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	110	844	6.6E+06	1.8E+00	6.2E-01	408800	3999.8	6.3E-03	2.0E-04	2.7E-06	5.4E-05	5.6E-06	2.3E-08	5.7E-05	6.9E-09	5.9E-09
1B	111	844	6.5E+06	1.7E+00	6.2E-01	412800	4000.2	6.1E-03	2.0E-04	2.7E-06	5.8E-05	5.6E-06	2.1E-08	5.8E-05	6.8E-09	6.0E-09
1B	112	844	6.6E+06	1.7E+00	6.2E-01	416800	4000	6.0E-03	2.1E-04	2.6E-06	6.2E-05	5.5E-06	2.0E-08	5.8E-05	6.8E-09	6.1E-09
1B	113	844	6.5E+06	1.7E+00	6.3E-01	420800	4000	5.9E-03	2.1E-04	2.6E-06	6.7E-05	5.4E-06	1.9E-08	5.9E-05	6.8E-09	6.2E-09
1B	114	820	4.6E+03	1.4E-03	3.9E-01	424800	20000	5.0E-05	2.0E-06	2.4E-08	7.7E-07	5.2E-08	1.4E-10	5.6E-07	6.4E-11	6.0E-11
1B	115	821	3.8E+03	1.1E-03	3.9E-01	424800	20000	4.1E-05	1.7E-06	2.0E-08	6.3E-07	4.3E-08	1.2E-10	4.6E-07	5.3E-11	5.0E-11
1B	116	844	6.5E+06	1.7E+00	6.3E-01	424800	3999.8	5.7E-03	2.1E-04	2.6E-06	7.1E-05	5.4E-06	1.7E-08	5.9E-05	6.9E-09	6.3E-09
1B	117	844	6.4E+06	1.7E+00	6.3E-01	428800	4000.2	5.6E-03	2.2E-04	2.5E-06	7.7E-05	5.5E-06	1.6E-08	6.0E-05	6.8E-09	6.4E-09
1B	118	844	6.4E+06	1.7E+00	6.3E-01	432800	4000	5.5E-03	2.2E-04	2.5E-06	8.4E-05	5.6E-06	1.5E-08	6.1E-05	6.8E-09	6.4E-09
1B	119	844	6.3E+06	1.7E+00	6.3E-01	436800	4000	5.4E-03	2.2E-04	2.6E-06	9.1E-05	5.9E-06	1.4E-08	6.1E-05	7.0E-09	6.7E-09
1B	120	844	6.3E+06	1.6E+00	6.3E-01	440800	3999.7	5.3E-03	2.3E-04	2.6E-06	9.8E-05	6.1E-06	1.3E-08	6.2E-05	7.1E-09	6.8E-09
1B	121	820	4.1E+03	1.2E-03	3.9E-01	444800	20000	4.4E-05	2.0E-06	2.4E-08	1.1E-06	6.9E-08	1.0E-10	5.3E-07	6.6E-11	6.5E-11
1B	122	821	3.4E+03	1.0E-03	3.9E-01	444800	20000	3.6E-05	1.6E-06	2.0E-08	9.3E-07	5.7E-08	8.5E-11	4.4E-07	5.5E-11	5.4E-11
1B	123	844	6.3E+06	1.6E+00	6.4E-01	444800	4000.4	5.1E-03	2.3E-04	2.6E-06	1.1E-04	6.5E-06	1.2E-08	6.2E-05	7.1E-09	6.9E-09
1B	124	844	6.2E+06	1.6E+00	6.4E-01	448800	3999.7	5.0E-03	2.4E-04	2.6E-06	1.2E-04	7.1E-06	1.2E-08	6.3E-05	7.1E-09	7.0E-09
1B	125	844	6.2E+06	1.6E+00	6.4E-01	452800	4000.1	4.9E-03	2.2E-04	2.6E-06	1.3E-04	7.6E-06	1.1E-08	5.9E-05	7.3E-09	7.2E-09
1B	126	844	6.1E+06	1.6E+00	6.4E-01	456800	4000.1	4.8E-03	2.0E-04	2.6E-06	1.3E-04	8.3E-06	1.0E-08	5.4E-05	7.4E-09	7.4E-09
1B	127	844	6.0E+06	1.6E+00	6.4E-01	460800	4000	4.7E-03	1.9E-04	2.7E-06	1.4E-04	9.0E-06	9.9E-09	4.9E-05	7.5E-09	7.6E-09
1B	128	820	3.7E+03	1.1E-03	3.9E-01	464800	24000	4.6E-05	1.6E-06	2.7E-08	2.0E-06	1.4E-07	8.7E-11	3.9E-07	8.3E-11	8.6E-11
1B	129	821	3.1E+03	9.1E-04	3.9E-01	464800	24000	3.8E-05	1.3E-06	2.2E-08	1.7E-06	1.2E-07	7.2E-11	3.2E-07	6.9E-11	7.1E-11
1B	130	844	6.0E+06	1.6E+00	6.4E-01	464800	3999.8	4.6E-03	1.7E-04	2.6E-06	1.5E-04	9.9E-06	9.3E-09	4.5E-05	7.6E-09	7.7E-09
1B	131	844	6.0E+06	1.5E+00	6.4E-01	468800	4000.2	4.5E-03	1.6E-04	2.6E-06	1.7E-04	1.1E-05	8.7E-09	4.1E-05	7.7E-09	7.8E-09
1B	132	844	5.9E+06	1.5E+00	6.4E-01	472800	3999.8	4.4E-03	1.5E-04	2.5E-06	1.8E-04	1.2E-05	8.2E-09	3.7E-05	7.6E-09	7.9E-09
1B	133	844	5.9E+06	1.5E+00	6.5E-01	476800	4000	4.3E-03	1.4E-04	2.4E-06	2.0E-04	1.4E-05	7.7E-09	3.3E-05	7.7E-09	8.0E-09
1B	134	844	5.8E+06	1.5E+00	6.5E-01	480800	3999.9	4.2E-03	1.3E-04	2.3E-06	2.1E-04	1.6E-05	7.2E-09	3.0E-05	7.7E-09	8.1E-09
1B	135	844	5.8E+06	1.5E+00	6.5E-01	484800	4000.2	4.1E-03	1.2E-04	2.3E-06	2.3E-04	1.7E-05	6.8E-09	2.7E-05	7.9E-09	8.4E-09
1B	136	820	3.3E+03	9.8E-04	3.8E-01	488800	20000	3.3E-05	9.0E-07	1.9E-08	2.6E-06	2.2E-07	5.1E-11	1.9E-07	7.3E-11	7.6E-11
1B	137	821	2.7E+03	8.1E-04	3.8E-01	488800	20000	2.7E-05	7.5E-07	1.6E-08	2.2E-06	1.8E-07	4.2E-11	1.5E-07	6.0E-11	6.3E-11
1B	138	824	1.6E+03	4.6E-04	3.8E-01	488800	20000	1.6E-05	4.3E-07	8.9E-09	1.2E-06	1.0E-07	2.4E-11	8.8E-08	3.4E-11	3.6E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	139	844	5.8E+06	1.5E+00	6.5E-01	488800	3999.8	4.0E-03	1.1E-04	2.2E-06	2.5E-04	2.0E-05	6.3E-09	2.5E-05	7.9E-09	8.6E-09
1B	140	844	5.7E+06	1.5E+00	6.5E-01	492800	4000.2	3.9E-03	1.1E-04	2.2E-06	2.8E-04	2.2E-05	6.0E-09	2.3E-05	8.1E-09	8.9E-09
1B	141	844	5.7E+06	1.5E+00	6.5E-01	496800	4000.1	3.9E-03	1.0E-04	2.1E-06	3.0E-04	2.5E-05	5.6E-09	2.0E-05	8.2E-09	8.9E-09
1B	142	844	5.7E+06	1.5E+00	6.5E-01	500800	3999.8	3.8E-03	9.6E-05	2.0E-06	3.3E-04	2.9E-05	5.3E-09	1.8E-05	8.4E-09	8.4E-09
1B	143	844	5.6E+06	1.5E+00	6.6E-01	504800	4000	3.7E-03	9.1E-05	2.0E-06	3.5E-04	3.2E-05	5.1E-09	1.7E-05	8.8E-09	8.2E-09
1B	144	820	3.0E+03	8.8E-04	3.8E-01	508800	24000	3.4E-05	7.6E-07	2.0E-08	3.2E-06	5.1E-07	5.0E-11	1.3E-07	1.1E-10	7.4E-11
1B	145	821	2.5E+03	7.2E-04	3.8E-01	508800	24000	2.8E-05	6.3E-07	1.6E-08	2.6E-06	4.2E-07	4.1E-11	1.0E-07	8.8E-11	6.1E-11
1B	146	824	1.4E+03	4.1E-04	3.8E-01	508800	24000	1.6E-05	3.6E-07	9.2E-09	1.5E-06	2.4E-07	2.3E-11	5.9E-08	5.0E-11	3.5E-11
1B	147	844	5.6E+06	1.4E+00	6.6E-01	508800	4000.2	3.6E-03	8.4E-05	2.0E-06	3.3E-04	3.6E-05	5.1E-09	1.5E-05	9.2E-09	7.9E-09
1B	148	844	5.6E+06	1.4E+00	6.6E-01	512800	3999.7	3.5E-03	7.9E-05	2.0E-06	3.2E-04	4.0E-05	4.9E-09	1.4E-05	9.6E-09	7.6E-09
1B	149	844	5.5E+06	1.4E+00	6.6E-01	516800	4000.1	3.5E-03	7.4E-05	1.9E-06	3.1E-04	4.6E-05	4.8E-09	1.2E-05	1.0E-08	7.2E-09
1B	150	844	5.5E+06	1.4E+00	6.6E-01	520800	4000	3.4E-03	6.9E-05	1.8E-06	3.0E-04	5.2E-05	4.7E-09	1.1E-05	1.0E-08	6.9E-09
1B	151	844	5.5E+06	1.4E+00	6.6E-01	524800	4000.2	3.3E-03	6.5E-05	1.8E-06	2.9E-04	5.9E-05	4.6E-09	1.0E-05	1.1E-08	6.7E-09
1B	152	844	5.4E+06	1.4E+00	6.6E-01	528800	3999.9	3.2E-03	6.2E-05	1.7E-06	2.9E-04	6.6E-05	4.5E-09	9.0E-06	1.2E-08	6.4E-09
1B	153	820	2.7E+03	7.8E-04	3.7E-01	532800	20000	2.5E-05	4.7E-07	1.4E-08	2.4E-06	7.8E-07	3.5E-11	5.7E-08	1.2E-10	5.0E-11
1B	154	821	2.2E+03	6.4E-04	3.7E-01	532800	20000	2.0E-05	3.9E-07	1.1E-08	1.9E-06	6.4E-07	2.9E-11	4.7E-08	1.0E-10	4.1E-11
1B	155	844	5.4E+06	1.4E+00	6.7E-01	532800	3999.9	3.2E-03	6.0E-05	1.7E-06	2.9E-04	7.6E-05	4.3E-09	8.1E-06	1.3E-08	6.1E-09
1B	156	844	5.4E+06	1.4E+00	6.7E-01	536800	4000	3.1E-03	5.8E-05	1.6E-06	2.9E-04	8.5E-05	4.3E-09	7.3E-06	1.4E-08	6.0E-09
1B	157	844	5.4E+06	1.4E+00	6.7E-01	540800	4000.2	3.0E-03	5.6E-05	1.6E-06	2.9E-04	9.4E-05	4.2E-09	6.5E-06	1.5E-08	5.9E-09
1B	158	844	5.3E+06	1.4E+00	6.7E-01	544800	4000	3.0E-03	5.3E-05	1.6E-06	2.7E-04	1.0E-04	4.2E-09	5.9E-06	1.6E-08	5.9E-09
1B	159	844	5.3E+06	1.3E+00	6.7E-01	548800	4000	2.9E-03	5.1E-05	1.6E-06	2.6E-04	1.1E-04	4.0E-09	5.3E-06	1.7E-08	5.7E-09
1B	160	820	2.4E+03	7.0E-04	3.7E-01	552800	20000	2.2E-05	3.7E-07	1.2E-08	1.8E-06	1.3E-06	3.0E-11	3.2E-08	1.9E-10	4.3E-11
1B	161	821	2.0E+03	5.8E-04	3.7E-01	552800	20000	1.8E-05	3.1E-07	9.8E-09	1.5E-06	1.0E-06	2.5E-11	2.7E-08	1.5E-10	3.5E-11
1B	162	844	5.3E+06	1.3E+00	6.7E-01	552800	4000	2.8E-03	4.8E-05	1.5E-06	2.4E-04	1.3E-04	3.9E-09	4.7E-06	1.9E-08	5.4E-09
1B	163	844	5.2E+06	1.3E+00	6.7E-01	556800	3999.8	2.8E-03	4.7E-05	1.5E-06	2.3E-04	1.4E-04	3.7E-09	4.3E-06	2.1E-08	5.3E-09
1B	164	844	5.2E+06	1.3E+00	6.8E-01	560800	4000	2.7E-03	4.5E-05	1.4E-06	2.2E-04	1.6E-04	3.6E-09	3.8E-06	2.3E-08	5.2E-09
1B	165	844	5.2E+06	1.3E+00	6.8E-01	564800	4000.1	2.7E-03	4.4E-05	1.4E-06	2.1E-04	1.7E-04	3.5E-09	3.4E-06	2.5E-08	5.1E-09
1B	166	844	5.2E+06	1.3E+00	6.8E-01	568800	4000.1	2.6E-03	4.3E-05	1.4E-06	2.1E-04	1.8E-04	3.4E-09	3.1E-06	2.8E-08	5.0E-09
1B	167	820	2.1E+03	6.2E-04	3.6E-01	572800	24000	2.2E-05	3.6E-07	2.0E-08	1.8E-06	1.8E-06	3.1E-11	2.0E-08	3.8E-10	4.7E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
1B	168	821	1.8E+03	5.1E-04	3.6E-01	572800	24000	1.8E-05	2.9E-07	1.6E-08	1.5E-06	1.5E-06	2.5E-11	1.7E-08	3.1E-10	3.9E-11
1B	169	824	1.0E+03	2.9E-04	3.6E-01	572800	24000	1.0E-05	1.7E-07	9.3E-09	8.5E-07	8.6E-07	1.4E-11	9.6E-09	1.8E-10	2.2E-11
1B	170	844	5.1E+06	1.3E+00	6.8E-01	572800	4000	2.5E-03	4.2E-05	1.4E-06	2.0E-04	1.9E-04	3.4E-09	2.7E-06	3.1E-08	5.0E-09
1B	171	844	5.1E+06	1.3E+00	6.8E-01	576800	4000	2.5E-03	4.0E-05	1.4E-06	1.9E-04	2.0E-04	3.3E-09	2.4E-06	3.4E-08	5.1E-09
1B	172	844	5.1E+06	1.3E+00	6.8E-01	580800	4000	2.4E-03	3.8E-05	1.4E-06	1.9E-04	2.0E-04	3.2E-09	2.2E-06	3.8E-08	5.0E-09
1B	173	844	5.1E+06	1.3E+00	6.9E-01	584800	4000	2.4E-03	3.6E-05	2.0E-06	1.9E-04	1.9E-04	3.2E-09	1.9E-06	4.2E-08	4.9E-09
1B	174	844	5.0E+06	1.3E+00	6.9E-01	588800	3999.7	2.3E-03	3.4E-05	2.9E-06	1.8E-04	1.9E-04	3.1E-09	1.7E-06	4.7E-08	4.8E-09
1B	175	844	5.0E+06	1.3E+00	6.9E-01	592800	4000	2.3E-03	3.3E-05	3.9E-06	1.8E-04	1.8E-04	3.1E-09	1.5E-06	5.2E-08	4.7E-09
1B	176	820	1.9E+03	5.6E-04	3.6E-01	596800	8000.2	6.6E-06	9.7E-08	1.2E-08	5.6E-07	5.8E-07	9.7E-12	4.0E-09	1.9E-10	1.5E-11
1B	177	821	1.6E+03	4.7E-04	3.6E-01	596800	8000.2	5.5E-06	8.0E-08	9.7E-09	4.6E-07	4.8E-07	8.0E-12	3.3E-09	1.6E-10	1.2E-11
1B	178	844	5.0E+06	1.2E+00	6.9E-01	596800	4000.2	2.2E-03	3.2E-05	3.9E-06	1.8E-04	1.9E-04	3.1E-09	1.4E-06	5.8E-08	4.7E-09
1B	179	844	5.0E+06	1.2E+00	6.9E-01	600800	4000	2.2E-03	3.0E-05	3.6E-06	1.8E-04	1.9E-04	3.2E-09	1.2E-06	6.5E-08	4.9E-09
2A	1	820	1.8E+03	4.5E-04	8.8E-01	48140	21600	1.9E-05	1.7E-06	5.1E-08	1.8E-06	1.7E-06	1.5E-08	3.8E-07	3.7E-13	3.7E-13
2A	2	820	1.6E+03	4.3E-04	7.6E-01	69740	21300	5.5E-05	1.1E-05	1.7E-07	1.0E-05	8.4E-06	5.1E-08	2.4E-06	7.0E-11	1.1E-11
2A	3	821	1.3E+03	3.6E-04	7.6E-01	69740	21300	4.6E-05	9.6E-06	1.4E-07	8.5E-06	7.0E-06	4.2E-08	2.1E-06	5.8E-11	9.5E-12
2A	4	824	7.7E+02	2.1E-04	7.6E-01	69740	21300	2.6E-05	5.5E-06	7.9E-08	4.9E-06	4.0E-06	2.4E-08	1.2E-06	3.4E-11	5.5E-12
2A	5	27	1.7E+07	4.0E+00	1.2E+00	76940	3600	6.7E-03	4.3E-04	2.4E-06	1.3E-04	1.0E-04	4.9E-07	1.1E-04	3.1E-10	7.9E-11
2A	6	844	2.5E+07	7.0E+00	7.5E-01	77476	3564.4	2.1E-01	6.8E-02	5.5E-04	3.2E-02	2.4E-02	1.1E-04	1.6E-02	1.7E-07	2.8E-08
2A	7	27	1.4E+07	3.2E+00	1.1E+00	80540	3599.9	1.3E-02	2.5E-04	2.2E-06	1.3E-04	9.1E-05	4.2E-07	6.0E-05	1.1E-09	1.4E-10
2A	8	844	2.0E+07	5.8E+00	7.3E-01	81040	3600	1.3E-01	3.2E-02	4.1E-04	2.7E-02	1.5E-02	7.1E-05	7.3E-03	6.2E-07	6.9E-08
2A	9	27	9.6E+06	2.3E+00	1.1E+00	84140	3900.1	1.4E-02	1.1E-04	1.1E-06	7.5E-05	4.8E-05	1.9E-07	2.3E-05	1.1E-09	1.5E-10
2A	10	844	1.2E+07	3.5E+00	7.1E-01	84640	3400	7.7E-02	3.4E-02	2.2E-04	2.5E-02	1.5E-02	3.4E-05	3.4E-03	3.1E-07	5.6E-08
2A	11	27	6.6E+06	1.6E+00	1.1E+00	88040	3000	8.0E-03	2.1E-05	1.8E-07	1.6E-05	9.2E-06	2.9E-08	3.3E-06	2.6E-10	4.6E-11
2A	12	844	3.0E+06	8.7E-01	7.0E-01	88040	4000	2.2E-02	5.8E-03	5.1E-05	6.0E-03	2.8E-03	7.2E-06	7.0E-04	2.3E-07	4.1E-08
2A	13	27	6.4E+06	1.5E+00	1.1E+00	91040	3999.9	1.1E-02	1.1E-05	9.3E-08	9.2E-06	4.6E-06	1.5E-08	1.8E-06	2.8E-10	4.7E-11
2A	14	844	9.1E+05	2.7E-01	6.9E-01	92040	2999.9	4.7E-03	9.1E-04	1.0E-05	1.3E-03	5.2E-04	1.1E-06	1.0E-04	1.0E-07	1.6E-08
2A	15	27	6.1E+06	1.5E+00	1.1E+00	95040	4000.1	1.1E-02	5.9E-06	5.6E-08	5.9E-06	2.7E-06	8.5E-09	1.0E-06	3.0E-10	4.9E-11
2A	16	844	4.2E+05	1.2E-01	6.8E-01	95040	4000.1	2.7E-03	2.8E-04	3.8E-06	5.5E-04	2.0E-04	3.4E-07	3.1E-05	5.7E-08	9.8E-09
2A	17	27	5.8E+06	1.4E+00	1.1E+00	99040	2999.9	7.8E-03	2.9E-06	3.0E-08	3.4E-06	1.5E-06	4.2E-09	5.0E-07	2.0E-10	3.6E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	18	844	4.9E+05	1.5E-01	6.6E-01	99040	3999.9	3.0E-03	1.6E-04	2.7E-06	4.1E-04	1.4E-04	1.8E-07	1.8E-05	3.8E-08	8.5E-09
2A	19	27	5.3E+06	1.3E+00	1.1E+00	102040	4000.2	9.6E-03	2.6E-06	2.8E-08	3.4E-06	1.4E-06	3.7E-09	4.4E-07	2.1E-10	4.2E-11
2A	20	844	1.0E+06	3.2E-01	6.5E-01	103040	3000.2	4.7E-03	1.7E-04	4.1E-06	5.8E-04	2.0E-04	2.0E-07	1.6E-05	4.2E-08	1.2E-08
2A	21	27	4.7E+06	1.1E+00	1.1E+00	106040	2999.9	6.4E-03	1.2E-06	1.4E-08	1.7E-06	6.9E-07	1.7E-09	2.1E-07	9.4E-11	2.2E-11
2A	22	844	1.6E+06	5.0E-01	6.3E-01	106040	3999.9	9.3E-03	2.6E-04	1.3E-05	1.2E-03	4.3E-04	3.4E-07	2.2E-05	7.1E-08	2.7E-08
2A	23	27	3.4E+06	8.3E-01	1.1E+00	109040	4000	6.2E-03	8.9E-07	9.9E-09	1.1E-06	4.6E-07	1.3E-09	1.6E-07	5.4E-11	1.2E-11
2A	24	844	2.8E+06	8.5E-01	6.2E-01	110040	3000	1.1E-02	2.7E-04	3.0E-05	1.4E-03	5.6E-04	3.9E-07	1.8E-05	7.8E-08	3.7E-08
2A	25	27	2.8E+06	6.8E-01	1.1E+00	113040	3000	3.7E-03	4.6E-07	5.5E-09	6.1E-07	2.5E-07	6.7E-10	8.0E-08	2.9E-11	7.0E-12
2A	26	844	3.6E+06	1.1E+00	6.3E-01	113040	4000.1	1.7E-02	3.8E-04	4.1E-05	2.0E-03	9.0E-04	5.8E-07	2.1E-05	1.1E-07	6.0E-08
2A	27	27	2.7E+06	6.4E-01	1.1E+00	116040	4000	4.5E-03	4.4E-07	5.7E-09	6.3E-07	2.5E-07	6.4E-10	7.7E-08	3.0E-11	7.5E-12
2A	28	844	3.8E+06	1.2E+00	6.3E-01	117040	3999.9	1.6E-02	3.8E-04	2.8E-05	1.9E-03	9.3E-04	5.5E-07	1.6E-05	9.9E-08	6.1E-08
2A	29	27	2.3E+06	5.5E-01	1.1E+00	120040	3999.9	3.8E-03	2.2E-07	3.0E-09	3.4E-07	1.3E-07	3.2E-10	3.9E-08	1.6E-11	4.0E-12
2A	30	844	4.1E+06	1.2E+00	6.4E-01	121040	2999.9	1.2E-02	3.2E-04	1.6E-05	1.4E-03	7.3E-04	4.1E-07	1.0E-05	6.9E-08	4.6E-08
2A	31	27	2.3E+06	5.6E-01	1.1E+00	124040	3000.1	2.8E-03	1.0E-07	1.4E-09	1.6E-07	5.8E-08	1.5E-10	1.7E-08	7.0E-12	1.8E-12
2A	32	844	4.3E+06	1.3E+00	6.4E-01	124040	4000.1	1.5E-02	5.0E-04	1.6E-05	2.0E-03	1.0E-03	5.4E-07	1.3E-05	8.6E-08	6.1E-08
2A	33	27	2.2E+06	5.3E-01	1.1E+00	127040	4000	3.4E-03	8.9E-08	1.2E-09	1.6E-07	5.2E-08	1.3E-10	1.5E-08	6.3E-12	1.6E-12
2A	34	844	4.4E+06	1.3E+00	6.4E-01	128040	3000	1.1E-02	4.4E-04	9.2E-06	1.7E-03	8.1E-04	4.0E-07	1.0E-05	6.0E-08	4.5E-08
2A	35	27	2.1E+06	5.1E-01	1.1E+00	131040	3000.1	2.4E-03	5.0E-08	6.8E-10	9.0E-08	2.9E-08	7.2E-11	8.5E-09	3.5E-12	9.3E-13
2A	36	844	4.5E+06	1.3E+00	6.4E-01	131040	4000.1	1.4E-02	6.0E-04	9.8E-06	2.6E-03	1.1E-03	5.4E-07	1.5E-05	7.6E-08	5.9E-08
2A	37	27	2.0E+06	4.8E-01	1.1E+00	134040	3999.9	2.9E-03	5.0E-08	6.9E-10	9.3E-08	2.9E-08	7.2E-11	8.5E-09	3.5E-12	9.3E-13
2A	38	844	4.5E+06	1.3E+00	6.4E-01	135040	3999.9	1.3E-02	6.5E-04	7.7E-06	2.8E-03	1.0E-03	5.4E-07	1.8E-05	7.0E-08	5.7E-08
2A	39	27	1.9E+06	4.5E-01	1.1E+00	138040	3999.9	2.7E-03	3.5E-08	4.9E-10	6.9E-08	2.1E-08	5.1E-11	6.0E-09	2.5E-12	6.7E-13
2A	40	844	4.6E+06	1.3E+00	6.4E-01	139040	2999.9	9.2E-03	5.3E-04	5.6E-06	2.4E-03	7.8E-04	4.3E-07	1.6E-05	5.1E-08	4.3E-08
2A	41	27	1.8E+06	4.3E-01	1.1E+00	142040	3000.1	1.8E-03	1.9E-08	2.7E-10	3.9E-08	1.1E-08	2.8E-11	3.3E-09	1.4E-12	3.7E-13
2A	42	844	4.7E+06	1.4E+00	6.4E-01	142040	4000.2	1.2E-02	6.6E-04	8.2E-06	3.6E-03	1.1E-03	6.1E-07	2.5E-05	6.6E-08	5.7E-08
2A	43	27	1.7E+06	4.0E-01	1.1E+00	145040	4000	2.2E-03	1.9E-08	2.6E-10	4.0E-08	1.1E-08	2.7E-11	3.2E-09	1.4E-12	3.6E-13
2A	44	844	4.8E+06	1.4E+00	6.4E-01	146040	2999.9	8.5E-03	5.0E-04	7.2E-06	3.1E-03	8.4E-04	4.9E-07	2.2E-05	4.8E-08	4.3E-08
2A	45	27	1.9E+06	4.5E-01	1.1E+00	149040	3999.9	2.5E-03	1.2E-07	1.6E-09	7.7E-07	1.8E-07	1.3E-10	7.8E-09	1.1E-11	8.8E-12
2A	46	844	4.8E+06	1.4E+00	6.0E-01	149040	3999.9	1.1E-02	6.8E-04	8.7E-06	4.9E-03	1.1E-03	7.0E-07	3.3E-05	6.1E-08	5.5E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	47	27	1.4E+06	3.3E-01	1.1E+00	153040	3000	1.3E-03	9.2E-09	1.3E-10	3.3E-08	8.1E-09	1.2E-11	1.3E-09	7.1E-13	3.3E-13
2A	48	844	5.0E+06	1.4E+00	6.4E-01	153040	4000.1	1.0E-02	6.7E-04	8.2E-06	5.0E-03	1.3E-03	7.9E-07	4.0E-05	6.2E-08	5.7E-08
2A	49	27	1.4E+06	3.3E-01	1.1E+00	156040	4000.2	1.7E-03	1.1E-08	1.5E-10	4.5E-08	1.1E-08	1.4E-11	1.4E-09	8.7E-13	4.6E-13
2A	50	844	5.1E+06	1.5E+00	6.4E-01	157040	3000.1	7.4E-03	4.5E-04	5.7E-06	3.1E-03	1.0E-03	6.3E-07	3.4E-05	4.6E-08	4.3E-08
2A	51	27	1.3E+06	3.1E-01	1.1E+00	160040	2999.9	1.2E-03	6.7E-09	9.1E-11	2.9E-08	7.0E-09	8.4E-12	8.1E-10	5.4E-13	3.0E-13
2A	52	844	5.1E+06	1.5E+00	6.4E-01	160040	3999.9	9.5E-03	5.5E-04	7.1E-06	3.5E-03	1.4E-03	8.9E-07	4.9E-05	6.0E-08	5.7E-08
2A	53	27	1.2E+06	3.0E-01	1.1E+00	163040	4000	1.4E-03	6.9E-09	9.3E-11	3.1E-08	7.3E-09	8.6E-12	8.0E-10	5.5E-13	3.2E-13
2A	54	844	5.2E+06	1.5E+00	6.4E-01	164040	3000	6.8E-03	3.8E-04	5.1E-06	2.2E-03	1.1E-03	7.0E-07	4.0E-05	4.5E-08	4.2E-08
2A	55	27	1.2E+06	2.8E-01	1.1E+00	167040	4000.1	1.3E-03	4.8E-09	6.6E-11	2.3E-08	5.3E-09	6.1E-12	5.7E-10	4.0E-13	2.3E-13
2A	56	844	5.3E+06	1.5E+00	6.4E-01	167040	4000.1	8.7E-03	4.6E-04	7.0E-06	2.4E-03	1.6E-03	9.5E-07	5.6E-05	5.8E-08	5.6E-08
2A	57	27	1.1E+06	2.6E-01	1.1E+00	171040	1400	4.3E-04	1.4E-09	1.9E-11	6.5E-09	1.5E-09	1.7E-12	1.6E-10	1.1E-13	6.5E-14
2A	58	844	5.4E+06	1.5E+00	6.4E-01	171040	5399.8	1.1E-02	5.7E-04	1.1E-05	2.6E-03	2.4E-03	1.3E-06	8.0E-05	7.7E-08	7.4E-08
2A	59	27	1.1E+06	2.5E-01	1.1E+00	172440	3999.8	1.1E-03	3.1E-09	4.2E-11	1.5E-08	3.4E-09	4.0E-12	3.6E-10	2.5E-13	1.5E-13
2A	60	27	9.8E+05	2.3E-01	1.1E+00	176440	4000.2	1.0E-03	2.2E-09	3.0E-11	1.1E-08	2.5E-09	2.7E-12	2.6E-10	1.8E-13	1.1E-13
2A	61	844	5.4E+06	1.6E+00	6.4E-01	176440	4000.2	7.7E-03	3.9E-04	8.8E-06	1.5E-03	1.9E-03	1.0E-06	6.2E-05	5.5E-08	5.4E-08
2A	62	27	9.3E+05	2.2E-01	1.1E+00	180440	3999.9	9.4E-04	1.5E-09	2.1E-11	7.7E-09	1.8E-09	1.9E-12	1.7E-10	1.3E-13	7.7E-14
2A	63	844	5.5E+06	1.6E+00	6.4E-01	180440	3999.9	7.3E-03	3.7E-04	9.8E-06	1.3E-03	1.9E-03	1.0E-06	6.3E-05	5.4E-08	5.3E-08
2A	64	27	8.7E+05	2.1E-01	1.1E+00	184440	4000.1	8.6E-04	1.1E-09	1.5E-11	5.6E-09	1.3E-09	1.4E-12	1.2E-10	9.1E-14	5.5E-14
2A	65	844	5.5E+06	1.6E+00	6.4E-01	184440	4000.1	6.9E-03	3.5E-04	1.1E-05	1.0E-03	2.0E-03	1.1E-06	6.3E-05	5.3E-08	5.3E-08
2A	66	27	8.2E+05	2.0E-01	1.1E+00	188440	3999.9	7.8E-04	8.7E-10	1.0E-11	4.0E-09	9.3E-10	1.3E-12	8.7E-11	6.5E-14	4.0E-14
2A	67	844	5.6E+06	1.6E+00	6.4E-01	188440	3999.9	6.5E-03	3.3E-04	1.2E-05	8.7E-04	2.0E-03	1.1E-06	6.3E-05	5.2E-08	5.2E-08
2A	68	27	7.7E+05	1.8E-01	1.1E+00	192440	4000	7.1E-04	5.2E-10	7.7E-12	2.9E-09	7.3E-10	6.8E-13	7.3E-11	4.6E-14	2.9E-14
2A	69	844	5.7E+06	1.6E+00	6.4E-01	192440	4000	6.2E-03	3.1E-04	1.4E-05	7.3E-04	1.9E-03	1.1E-06	6.2E-05	5.1E-08	5.1E-08
2A	70	27	7.2E+05	1.7E-01	1.1E+00	196440	4000.1	6.5E-04	3.5E-10	5.9E-12	2.1E-09	5.2E-10	4.5E-13	5.8E-11	3.4E-14	2.1E-14
2A	71	844	5.7E+06	1.6E+00	6.4E-01	196440	4000.1	5.9E-03	2.9E-04	1.5E-05	6.2E-04	1.9E-03	1.1E-06	6.1E-05	5.0E-08	5.0E-08
2A	72	27	6.8E+05	1.6E-01	1.1E+00	200440	3999.9	5.9E-04	2.9E-10	4.1E-12	1.5E-09	3.5E-10	4.5E-13	2.9E-11	2.4E-14	1.5E-14
2A	73	844	5.7E+06	1.7E+00	6.4E-01	200440	3999.9	5.6E-03	2.8E-04	1.7E-05	5.2E-04	1.9E-03	1.2E-06	5.9E-05	4.9E-08	4.9E-08
2A	74	27	6.3E+05	1.5E-01	1.1E+00	204440	3999.9	5.3E-04	2.3E-10	2.7E-12	1.1E-09	3.2E-10	2.3E-13	1.5E-11	1.6E-14	1.1E-14
2A	75	844	5.8E+06	1.7E+00	6.4E-01	204440	3999.9	5.3E-03	2.6E-04	1.8E-05	4.5E-04	1.9E-03	1.2E-06	5.7E-05	4.8E-08	4.8E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	76	27	5.9E+05	1.4E-01	1.1E+00	208440	4000.2	4.8E-04	1.2E-10	2.3E-12	7.3E-10	2.0E-10	2.3E-13	1.5E-11	1.2E-14	8.0E-15
2A	77	844	5.8E+06	1.7E+00	6.4E-01	208440	4000.2	5.0E-03	2.5E-04	1.7E-05	3.8E-04	2.0E-03	1.2E-06	5.5E-05	4.7E-08	4.7E-08
2A	78	27	5.6E+05	1.3E-01	1.1E+00	212440	3999.8	4.4E-04	5.8E-11	1.4E-12	5.5E-10	1.7E-10	0.0E+00	1.5E-11	8.4E-15	5.9E-15
2A	79	844	5.9E+06	1.7E+00	6.4E-01	212440	3999.8	4.8E-03	2.3E-04	1.6E-05	3.2E-04	2.0E-03	1.1E-06	5.3E-05	4.6E-08	4.6E-08
2A	80	27	5.3E+05	1.3E-01	1.1E+00	216440	4000	4.1E-04	1.2E-10	1.4E-12	3.8E-10	1.2E-10	2.3E-13	1.5E-11	6.2E-15	4.4E-15
2A	81	844	5.9E+06	1.7E+00	6.4E-01	216440	4000	4.5E-03	2.2E-04	1.4E-05	2.8E-04	2.0E-03	1.0E-06	5.1E-05	4.5E-08	4.5E-08
2A	82	27	5.0E+05	1.2E-01	1.1E+00	220440	4000.1	3.7E-04	0.0E+00	1.4E-12	2.9E-10	1.2E-10	0.0E+00	0.0E+00	4.4E-15	3.2E-15
2A	83	844	5.9E+06	1.7E+00	6.4E-01	220440	4000.1	4.3E-03	2.0E-04	1.2E-05	2.4E-04	2.1E-03	9.2E-07	4.9E-05	4.4E-08	4.4E-08
2A	84	27	4.8E+05	1.1E-01	1.1E+00	224440	4000	3.4E-04	1.2E-10	9.1E-13	2.0E-10	5.8E-11	0.0E+00	1.5E-11	3.6E-15	2.4E-15
2A	85	844	5.9E+06	1.7E+00	6.4E-01	224440	4000	4.1E-03	1.9E-04	1.1E-05	2.1E-04	2.2E-03	8.5E-07	4.7E-05	4.3E-08	4.3E-08
2A	86	27	4.5E+05	1.1E-01	1.1E+00	228440	4000	3.1E-04	0.0E+00	0.0E+00	8.7E-11	5.8E-11	0.0E+00	0.0E+00	1.8E-15	1.7E-15
2A	87	844	6.0E+06	1.7E+00	6.4E-01	228440	4000	3.9E-03	1.8E-04	9.8E-06	1.8E-04	2.3E-03	7.9E-07	4.5E-05	4.2E-08	4.2E-08
2A	88	27	4.3E+05	1.0E-01	1.1E+00	232440	4000	2.9E-04	0.0E+00	9.1E-13	1.2E-10	5.8E-11	0.0E+00	0.0E+00	1.8E-15	1.1E-15
2A	89	844	6.0E+06	1.7E+00	6.4E-01	232440	4000	3.7E-03	1.7E-04	9.0E-06	1.6E-04	2.5E-03	7.5E-07	4.3E-05	4.2E-08	4.2E-08
2A	90	27	4.1E+05	9.7E-02	1.1E+00	236440	4000	2.7E-04	0.0E+00	0.0E+00	2.9E-11	0.0E+00	2.3E-13	0.0E+00	8.9E-16	6.7E-16
2A	91	844	6.0E+06	1.7E+00	6.4E-01	236440	4000	3.6E-03	1.6E-04	8.5E-06	1.4E-04	2.6E-03	7.1E-07	4.0E-05	4.1E-08	4.2E-08
2A	92	27	3.8E+05	9.1E-02	1.1E+00	240440	4000	2.4E-04	0.0E+00	0.0E+00	2.9E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-16
2A	93	844	6.0E+06	1.7E+00	6.4E-01	240440	4000	3.4E-03	1.5E-04	8.1E-06	1.3E-04	2.5E-03	6.8E-07	3.8E-05	4.2E-08	4.2E-08
2A	94	27	3.7E+05	8.8E-02	1.1E+00	244440	4000.1	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	95	844	6.0E+06	1.7E+00	6.4E-01	244440	4000.1	3.2E-03	1.4E-04	7.9E-06	1.1E-04	2.6E-03	6.5E-07	3.6E-05	4.3E-08	4.3E-08
2A	96	27	3.8E+05	8.9E-02	1.1E+00	248440	4000	2.2E-04	0.0E+00	0.0E+00	2.9E-11	0.0E+00	0.0E+00	0.0E+00	4.4E-16	0.0E+00
2A	97	844	6.0E+06	1.7E+00	6.5E-01	248440	4000	3.1E-03	1.3E-04	8.0E-06	1.0E-04	2.7E-03	6.3E-07	3.5E-05	4.4E-08	4.5E-08
2A	98	27	3.9E+05	9.3E-02	1.1E+00	252440	3999.9	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	99	844	6.0E+06	1.7E+00	6.5E-01	252440	3999.9	2.9E-03	1.3E-04	8.2E-06	9.1E-05	3.0E-03	6.1E-07	1.0E-04	4.6E-08	4.6E-08
2A	100	27	3.4E+05	8.1E-02	1.1E+00	256440	4000	1.9E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-11	0.0E+00	1.1E-16
2A	101	844	6.3E+06	1.8E+00	6.5E-01	256440	4000	2.9E-03	1.0E-04	7.7E-06	6.9E-05	2.5E-03	5.0E-07	6.2E-02	4.2E-08	4.3E-08
2A	102	27	4.0E+05	9.6E-02	1.1E+00	260440	4000.1	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-11	0.0E+00	0.0E+00
2A	103	844	6.2E+06	1.8E+00	6.4E-01	260440	4000.1	2.7E-03	8.7E-05	7.1E-06	5.1E-05	1.5E-03	4.0E-07	3.4E-02	3.7E-08	3.8E-08
2A	104	27	4.1E+05	9.8E-02	1.1E+00	264440	3999.9	2.2E-04	0.0E+00	0.0E+00	0.0E+00	5.8E-11	0.0E+00	1.5E-11	0.0E+00	0.0E+00

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	105	844	6.3E+06	1.8E+00	6.4E-01	264440	3999.9	2.6E-03	8.3E-05	7.3E-06	4.1E-05	1.0E-03	3.6E-07	2.2E-02	3.7E-08	3.8E-08
2A	106	27	4.3E+05	1.0E-01	1.1E+00	268440	4000.1	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-11	0.0E+00	5.6E-17
2A	107	844	6.3E+06	1.8E+00	6.4E-01	268440	4000.1	2.4E-03	8.3E-05	7.2E-06	3.6E-05	7.1E-04	3.4E-07	1.5E-02	3.7E-08	3.7E-08
2A	108	27	4.7E+05	1.1E-01	1.1E+00	272440	4000	2.3E-04	0.0E+00	0.0E+00	2.9E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	109	844	6.3E+06	1.8E+00	6.4E-01	272440	4000	2.3E-03	8.7E-05	8.1E-06	3.4E-05	5.2E-04	3.4E-07	1.1E-02	4.1E-08	4.1E-08
2A	110	27	4.9E+05	1.2E-01	1.1E+00	276440	3999.9	2.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-11	0.0E+00	0.0E+00
2A	111	844	6.3E+06	1.9E+00	6.5E-01	276440	3999.9	2.2E-03	9.3E-05	8.6E-06	3.3E-05	4.0E-04	3.6E-07	8.4E-03	4.3E-08	4.4E-08
2A	112	27	4.8E+05	1.1E-01	1.1E+00	280440	4000	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	113	844	6.4E+06	1.9E+00	6.4E-01	280440	4000	2.1E-03	1.0E-04	9.0E-06	3.3E-05	3.1E-04	3.8E-07	6.5E-03	4.6E-08	4.6E-08
2A	114	27	4.8E+05	1.1E-01	1.1E+00	284440	3999.9	2.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	115	844	6.4E+06	1.9E+00	6.5E-01	284440	3999.9	2.0E-03	1.1E-04	9.1E-06	3.2E-05	2.4E-04	4.0E-07	5.0E-03	4.7E-08	4.7E-08
2A	116	27	5.5E+05	1.3E-01	1.1E+00	288440	4000	2.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	117	844	6.3E+06	1.9E+00	6.5E-01	288440	4000	1.9E-03	1.1E-04	1.0E-05	3.2E-05	1.9E-04	4.2E-07	3.8E-03	5.1E-08	5.1E-08
2A	118	27	5.8E+05	1.4E-01	1.1E+00	292440	4000.1	2.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	119	844	6.2E+06	1.8E+00	6.5E-01	292440	4000.1	1.8E-03	1.1E-04	1.1E-05	3.2E-05	1.5E-04	4.4E-07	3.0E-03	5.5E-08	5.5E-08
2A	120	27	6.1E+05	1.5E-01	1.1E+00	296440	4000	2.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	121	844	6.2E+06	1.9E+00	6.5E-01	296440	4000	1.7E-03	1.1E-04	1.2E-05	3.2E-05	1.2E-04	4.6E-07	2.4E-03	5.9E-08	5.9E-08
2A	122	27	6.4E+05	1.5E-01	1.1E+00	300440	4000	2.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-11	0.0E+00	0.0E+00
2A	123	844	6.2E+06	1.9E+00	6.5E-01	300440	4000	1.6E-03	1.1E-04	1.2E-05	3.2E-05	1.0E-04	4.8E-07	1.9E-03	6.2E-08	6.2E-08
2A	124	27	6.6E+05	1.6E-01	1.1E+00	304440	4000	2.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	125	844	6.2E+06	1.9E+00	6.5E-01	304440	4000	1.6E-03	1.0E-04	1.3E-05	3.2E-05	8.3E-05	5.0E-07	1.5E-03	6.4E-08	6.5E-08
2A	126	27	6.8E+05	1.6E-01	1.1E+00	308440	4000	2.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	127	844	6.3E+06	1.9E+00	6.5E-01	308440	4000	1.5E-03	1.0E-04	1.3E-05	3.2E-05	7.0E-05	5.2E-07	1.2E-03	6.6E-08	6.7E-08
2A	128	27	6.8E+05	1.6E-01	1.1E+00	312440	3999.9	2.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	129	844	6.3E+06	1.9E+00	6.5E-01	312440	3999.9	1.4E-03	9.9E-05	1.3E-05	3.2E-05	5.9E-05	5.4E-07	9.6E-04	6.7E-08	6.8E-08
2A	130	27	6.9E+05	1.6E-01	1.1E+00	316440	4000.1	2.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	131	844	6.3E+06	1.9E+00	6.5E-01	316440	4000.1	1.4E-03	9.7E-05	1.4E-05	3.2E-05	5.0E-05	5.6E-07	7.7E-04	6.9E-08	6.9E-08
2A	132	27	6.8E+05	1.6E-01	1.1E+00	320440	4000.1	2.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	133	844	6.3E+06	1.9E+00	6.5E-01	320440	4000.1	1.3E-03	9.4E-05	1.4E-05	3.2E-05	4.4E-05	5.7E-07	6.2E-04	6.8E-08	6.9E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	134	27	7.0E+05	1.7E-01	1.1E+00	324440	3999.9	2.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	135	844	6.3E+06	1.9E+00	6.5E-01	324440	3999.9	1.3E-03	9.1E-05	1.4E-05	3.1E-05	3.8E-05	5.8E-07	5.0E-04	6.9E-08	6.9E-08
2A	136	27	7.1E+05	1.7E-01	1.1E+00	328440	4000	2.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	137	844	6.3E+06	1.9E+00	6.5E-01	328440	4000	1.2E-03	8.8E-05	1.4E-05	3.1E-05	3.4E-05	5.9E-07	4.0E-04	6.9E-08	7.0E-08
2A	138	27	7.2E+05	1.7E-01	1.1E+00	332440	4000	2.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	139	844	6.3E+06	1.9E+00	6.5E-01	332440	4000	1.2E-03	8.5E-05	1.4E-05	3.0E-05	3.0E-05	6.0E-07	3.2E-04	7.0E-08	7.0E-08
2A	140	27	6.7E+05	1.6E-01	1.1E+00	336440	3999.9	2.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	141	844	6.4E+06	1.9E+00	6.5E-01	336440	3999.9	1.1E-03	8.3E-05	1.3E-05	3.0E-05	2.7E-05	6.1E-07	2.7E-04	6.8E-08	6.8E-08
2A	142	27	6.7E+05	1.6E-01	1.1E+00	340440	4000.2	2.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	143	844	6.4E+06	1.9E+00	6.5E-01	340440	4000.2	1.1E-03	7.9E-05	1.2E-05	2.9E-05	2.3E-05	6.0E-07	2.1E-04	6.4E-08	6.4E-08
2A	144	27	1.1E+06	2.5E-01	1.1E+00	344440	3999.9	3.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	145	844	5.0E+06	1.5E+00	6.7E-01	344440	3999.9	8.9E-04	7.6E-05	8.1E-06	4.0E-05	2.8E-05	4.8E-07	1.5E-04	4.2E-08	4.2E-08
2A	146	27	1.7E+06	4.1E-01	1.2E+00	348440	4000	4.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	147	844	3.5E+06	1.0E+00	6.9E-01	348440	4000	6.4E-04	5.2E-05	4.8E-06	3.1E-05	1.8E-05	3.0E-07	7.6E-05	2.5E-08	2.4E-08
2A	148	27	1.8E+06	4.2E-01	1.2E+00	352440	3999.9	4.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	149	844	3.4E+06	1.0E+00	6.9E-01	352440	3999.9	6.2E-04	5.5E-05	5.1E-06	3.4E-05	1.6E-05	3.0E-07	6.4E-05	2.6E-08	2.6E-08
2A	150	27	1.8E+06	4.2E-01	1.2E+00	356440	4000.2	4.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	151	844	3.4E+06	1.0E+00	7.0E-01	356440	4000.2	6.0E-04	5.7E-05	5.3E-06	3.6E-05	1.5E-05	3.1E-07	5.4E-05	2.7E-08	2.7E-08
2A	152	27	1.8E+06	4.2E-01	1.2E+00	360440	3999.9	4.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	153	844	3.4E+06	1.0E+00	6.9E-01	360440	3999.9	5.8E-04	5.9E-05	5.6E-06	3.8E-05	1.4E-05	3.1E-07	4.6E-05	2.9E-08	2.8E-08
2A	154	27	1.7E+06	4.1E-01	1.2E+00	364440	4000	4.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	155	844	3.5E+06	1.0E+00	7.0E-01	364440	4000	5.8E-04	6.2E-05	8.5E-06	4.0E-05	1.3E-05	3.2E-07	4.0E-05	2.9E-08	2.9E-08
2A	156	27	1.7E+06	4.1E-01	1.2E+00	368440	3999.9	4.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-16
2A	157	844	3.5E+06	1.0E+00	7.0E-01	368440	3999.9	5.6E-04	6.2E-05	1.2E-05	4.0E-05	1.2E-05	3.2E-07	3.3E-05	2.8E-08	2.8E-08
2A	158	27	1.7E+06	4.1E-01	1.2E+00	372440	4000.1	4.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	159	844	3.5E+06	1.0E+00	7.0E-01	372440	4000.1	5.5E-04	6.3E-05	1.5E-05	4.1E-05	1.1E-05	3.2E-07	2.9E-05	2.8E-08	2.8E-08
2A	160	27	1.7E+06	3.9E-01	1.2E+00	376440	4000.1	3.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	161	844	3.6E+06	1.0E+00	7.0E-01	376440	4000.1	5.5E-04	6.4E-05	1.8E-05	4.2E-05	9.8E-06	3.3E-07	2.5E-05	2.8E-08	2.8E-08
2A	162	27	1.6E+06	3.9E-01	1.2E+00	380440	3999.9	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	163	844	3.6E+06	1.0E+00	7.0E-01	380440	3999.9	5.4E-04	6.3E-05	1.7E-05	4.2E-05	9.0E-06	3.3E-07	2.2E-05	2.7E-08	2.7E-08
2A	164	27	1.6E+06	3.8E-01	1.2E+00	384440	4000	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	165	844	3.6E+06	1.0E+00	7.0E-01	384440	4000	5.3E-04	5.9E-05	1.5E-05	4.2E-05	8.2E-06	3.3E-07	1.9E-05	2.6E-08	2.6E-08
2A	166	27	1.6E+06	3.8E-01	1.2E+00	388440	4000	3.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.4E-16	5.6E-17
2A	167	844	3.6E+06	1.0E+00	7.0E-01	388440	4000	5.1E-04	5.6E-05	1.3E-05	4.2E-05	7.5E-06	3.3E-07	1.7E-05	2.5E-08	2.6E-08
2A	168	27	1.6E+06	3.8E-01	1.2E+00	392440	3999.9	3.2E-04	0.0E+00	4.5E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	169	844	3.7E+06	1.0E+00	7.0E-01	392440	3999.9	5.0E-04	5.3E-05	1.2E-05	4.2E-05	6.8E-06	3.3E-07	1.5E-05	2.6E-08	2.6E-08
2A	170	27	1.6E+06	3.7E-01	1.2E+00	396440	4000.1	3.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	171	844	3.7E+06	1.0E+00	7.0E-01	396440	4000.1	4.9E-04	5.0E-05	1.1E-05	4.1E-05	6.0E-06	3.2E-07	1.3E-05	2.6E-08	2.6E-08
2A	172	27	1.6E+06	3.7E-01	1.2E+00	400440	3999.9	3.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	173	844	3.7E+06	1.0E+00	7.0E-01	400440	3999.9	4.8E-04	4.7E-05	9.6E-06	4.1E-05	5.3E-06	3.1E-07	1.2E-05	2.6E-08	2.6E-08
2A	174	27	1.6E+06	3.7E-01	1.2E+00	404440	4000.2	2.9E-04	0.0E+00	9.1E-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	175	844	3.6E+06	1.0E+00	7.0E-01	404440	4000.2	4.6E-04	4.3E-05	8.3E-06	4.1E-05	6.1E-06	2.8E-07	1.4E-05	2.4E-08	2.4E-08
2A	176	27	1.9E+06	4.4E-01	1.2E+00	408440	3999.9	3.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	177	844	3.1E+06	8.9E-01	7.0E-01	408440	3999.9	3.9E-04	3.6E-05	5.5E-06	4.0E-05	1.1E-05	2.0E-07	2.7E-05	1.8E-08	1.7E-08
2A	178	27	2.1E+06	5.1E-01	1.2E+00	412440	4000	3.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-16
2A	179	844	2.6E+06	7.5E-01	7.1E-01	412440	4000	3.2E-04	2.9E-05	3.7E-06	3.7E-05	1.3E-05	1.4E-07	3.3E-05	1.3E-08	1.2E-08
2A	180	27	2.7E+06	6.5E-01	1.2E+00	416440	3999.9	4.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	181	844	1.6E+06	4.5E-01	7.1E-01	416440	3999.9	1.9E-04	1.5E-05	1.5E-06	2.3E-05	9.3E-06	6.7E-08	2.4E-05	5.7E-09	5.2E-09
2A	182	27	2.8E+06	6.5E-01	1.2E+00	420440	4000.1	4.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.4E-16	5.6E-17
2A	183	844	1.5E+06	4.4E-01	7.1E-01	420440	4000.1	1.8E-04	1.3E-05	1.4E-06	2.0E-05	7.6E-06	6.3E-08	1.9E-05	5.6E-09	5.2E-09
2A	184	27	2.8E+06	6.6E-01	1.2E+00	424440	4000	4.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	185	844	1.5E+06	4.3E-01	7.2E-01	424440	4000	1.7E-04	1.1E-05	1.3E-06	1.8E-05	6.2E-06	6.0E-08	1.5E-05	5.7E-09	5.4E-09
2A	186	27	2.7E+06	6.5E-01	1.2E+00	428440	4000	4.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	187	844	1.6E+06	4.4E-01	7.2E-01	428440	4000	1.7E-04	1.0E-05	1.4E-06	1.8E-05	5.5E-06	6.2E-08	1.3E-05	6.3E-09	6.0E-09
2A	188	27	2.7E+06	6.4E-01	1.2E+00	432440	4000	4.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	189	844	1.6E+06	4.5E-01	7.2E-01	432440	4000	1.7E-04	9.1E-06	1.4E-06	1.8E-05	4.8E-06	6.3E-08	1.1E-05	6.6E-09	6.3E-09
2A	190	27	2.8E+06	6.6E-01	1.2E+00	436440	4000	4.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	191	844	1.5E+06	4.2E-01	7.2E-01	436440	4000	1.6E-04	7.5E-06	1.3E-06	1.6E-05	3.8E-06	5.8E-08	8.9E-06	6.2E-09	6.0E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	192	27	2.7E+06	6.4E-01	1.2E+00	440440	4000	3.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	193	844	1.6E+06	4.5E-01	7.2E-01	440440	4000	1.7E-04	7.2E-06	1.4E-06	1.6E-05	3.5E-06	6.3E-08	8.0E-06	6.9E-09	6.7E-09
2A	194	27	2.7E+06	6.4E-01	1.2E+00	444440	3999.9	3.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	195	844	1.6E+06	4.5E-01	7.2E-01	444440	3999.9	1.6E-04	6.5E-06	1.3E-06	1.6E-05	3.0E-06	6.2E-08	6.8E-06	6.8E-09	6.7E-09
2A	196	27	2.7E+06	6.4E-01	1.2E+00	448440	4000.1	3.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	197	844	1.6E+06	4.5E-01	7.2E-01	448440	4000.1	1.6E-04	5.9E-06	1.2E-06	1.5E-05	2.6E-06	6.2E-08	5.6E-06	6.6E-09	6.5E-09
2A	198	27	2.7E+06	6.3E-01	1.2E+00	452440	4000	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	199	844	1.6E+06	4.5E-01	7.2E-01	452440	4000	1.6E-04	5.4E-06	1.2E-06	1.4E-05	2.3E-06	6.1E-08	4.7E-06	6.4E-09	6.3E-09
2A	200	27	2.7E+06	6.3E-01	1.2E+00	456440	4000	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	201	844	1.6E+06	4.5E-01	7.2E-01	456440	4000	1.5E-04	5.0E-06	1.1E-06	1.4E-05	2.0E-06	6.1E-08	4.0E-06	6.3E-09	6.3E-09
2A	202	27	2.7E+06	6.4E-01	1.2E+00	460440	4000.1	3.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	203	844	1.6E+06	4.5E-01	7.2E-01	460440	4000.1	1.5E-04	4.6E-06	1.1E-06	1.3E-05	1.7E-06	6.0E-08	3.3E-06	6.2E-09	6.2E-09
2A	204	27	2.8E+06	6.7E-01	1.2E+00	464440	3999.9	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	205	844	1.5E+06	4.3E-01	7.2E-01	464440	3999.9	1.4E-04	4.1E-06	1.1E-06	1.3E-05	1.4E-06	5.7E-08	2.7E-06	5.9E-09	5.9E-09
2A	206	27	2.8E+06	6.5E-01	1.2E+00	468440	4000	3.2E-04	0.0E+00	0.0E+00	2.9E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	207	844	1.6E+06	4.5E-01	7.2E-01	468440	4000	1.4E-04	4.1E-06	1.1E-06	1.3E-05	1.3E-06	5.9E-08	2.4E-06	6.4E-09	6.4E-09
2A	208	27	2.7E+06	6.4E-01	1.2E+00	472440	4000.1	3.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	209	844	1.6E+06	4.5E-01	7.1E-01	472440	4000.1	1.4E-04	3.9E-06	1.1E-06	1.3E-05	1.1E-06	5.8E-08	2.1E-06	6.3E-09	6.4E-09
2A	210	27	2.7E+06	6.4E-01	1.2E+00	476440	3506.5	2.6E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.4E-16	5.6E-17
2A	211	844	1.6E+06	4.4E-01	7.2E-01	476440	4199.8	1.4E-04	3.8E-06	1.1E-06	1.3E-05	1.0E-06	5.9E-08	1.9E-06	6.5E-09	6.5E-09
2A	212	27	2.7E+06	6.4E-01	1.2E+00	479950	4693.4	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
2A	213	844	1.6E+06	4.4E-01	7.2E-01	480640	4000.1	1.3E-04	3.5E-06	1.1E-06	1.2E-05	8.5E-07	5.5E-08	1.5E-06	6.1E-09	6.2E-09
2A	214	27	2.7E+06	6.4E-01	1.2E+00	484640	4000	2.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	215	844	1.6E+06	4.3E-01	7.2E-01	484640	4000	1.3E-04	3.3E-06	1.1E-06	1.2E-05	7.5E-07	5.3E-08	1.3E-06	6.1E-09	6.1E-09
2A	216	27	2.7E+06	6.3E-01	1.2E+00	488640	4000	2.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	217	844	1.6E+06	4.4E-01	7.2E-01	488640	4000	1.3E-04	3.3E-06	1.1E-06	1.2E-05	6.9E-07	5.4E-08	1.1E-06	6.2E-09	6.2E-09
2A	218	27	2.7E+06	6.4E-01	1.2E+00	492640	2703.5	1.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-17
2A	219	844	1.5E+06	4.2E-01	7.2E-01	492640	2703.5	8.0E-05	2.1E-06	6.8E-07	7.2E-06	3.9E-07	3.4E-08	6.4E-07	3.9E-09	4.0E-09
2A	220	27	1.0E+07	2.4E+00	1.1E+00	495340	1296.5	3.2E-04	4.0E-09	1.4E-09	1.4E-08	7.0E-10	6.6E-11	1.2E-09	7.8E-12	7.8E-12

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2A	221	844	1.2E+06	3.4E-01	5.0E-01	495340	1296.5	3.0E-05	7.2E-07	2.5E-07	2.6E-06	1.3E-07	1.2E-08	2.2E-07	1.4E-09	1.4E-09
2A	222	27	1.3E+07	3.0E+00	1.1E+00	496640	7000.1	1.9E-03	4.9E-08	1.7E-08	1.8E-07	8.0E-09	8.0E-10	1.4E-08	9.7E-11	9.7E-11
2R1	1	820	1.6E+03	4.1E-04	9.1E-01	48140	21600	3.4E-06	4.2E-07	3.1E-08	3.8E-07	3.8E-07	2.4E-09	7.1E-08	3.9E-14	3.9E-14
2R1	2	821	1.4E+03	3.4E-04	9.1E-01	48140	21600	2.8E-06	3.5E-07	2.5E-08	3.1E-07	3.1E-07	2.0E-09	5.9E-08	3.2E-14	3.2E-14
2R1	3	824	7.7E+02	1.9E-04	9.1E-01	48140	21600	1.6E-06	2.0E-07	1.5E-08	1.8E-07	1.8E-07	1.1E-09	3.3E-08	1.8E-14	1.8E-14
2R1	4	820	1.8E+03	4.5E-04	8.9E-01	69740	21300	1.9E-05	1.7E-06	3.2E-08	1.6E-06	1.6E-06	4.1E-08	4.1E-07	1.7E-12	1.7E-12
2R1	5	821	1.5E+03	3.7E-04	9.0E-01	69740	21300	1.6E-05	1.4E-06	2.7E-08	1.3E-06	1.3E-06	3.3E-08	3.4E-07	1.4E-12	1.4E-12
2R1	6	824	8.4E+02	2.1E-04	9.0E-01	69740	21300	9.0E-06	7.9E-07	1.5E-08	7.5E-07	7.4E-07	1.9E-08	1.9E-07	7.9E-13	7.9E-13
2R1	7	820	2.1E+03	5.4E-04	8.5E-01	91040	22000	4.0E-05	1.2E-05	1.3E-07	5.6E-06	5.6E-06	9.7E-08	2.9E-06	2.1E-10	1.5E-10
2R1	8	821	1.7E+03	4.5E-04	8.5E-01	91040	22000	3.3E-05	9.8E-06	1.1E-07	4.6E-06	4.6E-06	8.0E-08	2.4E-06	1.8E-10	1.2E-10
2R1	9	824	1.0E+03	2.5E-04	8.5E-01	91040	22000	1.9E-05	5.6E-06	6.2E-08	2.6E-06	2.6E-06	4.6E-08	1.4E-06	1.0E-10	7.1E-11
2R1	10	820	2.6E+03	6.9E-04	7.6E-01	113040	22000	1.2E-04	1.1E-05	1.6E-07	6.7E-06	5.7E-06	1.0E-06	2.6E-06	8.1E-09	7.2E-09
2R1	11	821	2.2E+03	5.7E-04	7.6E-01	113040	22000	9.8E-05	8.9E-06	1.3E-07	5.5E-06	4.7E-06	8.3E-07	2.1E-06	6.7E-09	5.9E-09
2R1	12	824	1.2E+03	3.3E-04	7.6E-01	113040	22000	5.6E-05	5.1E-06	7.4E-08	3.2E-06	2.7E-06	4.7E-07	1.2E-06	3.8E-09	3.4E-09
2R1	13	27	3.6E+06	8.6E-01	1.2E+00	127040	3999.8	6.4E-07	4.2E-12	6.6E-14	3.2E-12	2.4E-12	1.5E-12	1.0E-12	4.7E-15	3.6E-15
2R1	14	27	3.6E+06	8.6E-01	1.2E+00	131040	4000.1	7.4E-07	2.9E-12	4.5E-14	2.8E-12	1.8E-12	1.6E-12	6.9E-13	2.8E-15	2.1E-15
2R1	15	27	3.6E+06	8.6E-01	1.2E+00	135040	3000	6.1E-07	1.7E-12	2.7E-14	2.0E-12	1.2E-12	9.1E-13	4.0E-13	1.3E-15	9.6E-16
2R1	16	820	3.1E+03	8.3E-04	6.9E-01	135040	21000	1.4E-04	1.9E-06	6.6E-08	3.4E-06	2.0E-06	3.6E-07	4.2E-07	4.0E-10	2.6E-10
2R1	17	821	2.6E+03	6.9E-04	6.9E-01	135040	21000	1.1E-04	1.5E-06	5.5E-08	2.8E-06	1.7E-06	2.9E-07	3.4E-07	3.3E-10	2.2E-10
2R1	18	824	1.5E+03	3.9E-04	6.9E-01	135040	21000	6.5E-05	8.8E-07	3.1E-08	1.6E-06	9.6E-07	1.7E-07	2.0E-07	1.9E-10	1.2E-10
2R1	19	27	3.6E+06	8.6E-01	1.2E+00	138040	4000	9.0E-07	2.0E-12	3.6E-14	2.7E-12	1.7E-12	8.6E-13	4.8E-13	1.2E-15	8.3E-16
2R1	20	27	3.6E+06	8.6E-01	1.2E+00	142040	2999.9	7.4E-07	1.6E-12	3.3E-14	2.5E-12	1.5E-12	4.5E-13	3.8E-13	6.0E-16	4.2E-16
2R1	21	27	3.6E+06	8.6E-01	1.2E+00	145040	4000	1.1E-06	2.3E-12	5.8E-14	3.9E-12	2.3E-12	4.3E-13	5.2E-13	5.8E-16	4.0E-16
2R1	22	27	3.7E+06	8.6E-01	1.2E+00	149040	4000	1.2E-06	2.1E-12	7.6E-14	4.4E-12	2.3E-12	3.0E-13	4.8E-13	4.2E-16	2.8E-16
2R1	23	27	3.7E+06	8.6E-01	1.2E+00	153040	3000.1	9.4E-07	1.5E-12	7.3E-14	4.0E-12	1.7E-12	1.7E-13	3.2E-13	2.5E-16	1.7E-16
2R1	24	27	3.7E+06	8.7E-01	1.2E+00	156040	4000	1.3E-06	1.8E-12	1.2E-13	7.0E-12	2.2E-12	1.8E-13	3.7E-13	2.7E-16	1.9E-16
2R1	25	820	3.3E+03	9.9E-04	6.1E-01	156040	20484	1.5E-04	8.5E-07	1.2E-07	3.8E-06	2.0E-06	5.3E-08	1.5E-07	1.1E-10	8.2E-11
2R1	26	821	2.8E+03	8.2E-04	6.2E-01	156040	20484	1.2E-04	7.1E-07	9.7E-08	3.1E-06	1.7E-06	4.4E-08	1.2E-07	9.1E-11	6.8E-11
2R1	27	824	1.6E+03	4.7E-04	6.2E-01	156040	20484	7.1E-05	4.1E-07	5.6E-08	1.8E-06	9.7E-07	2.5E-08	7.0E-08	5.2E-11	3.9E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	28	27	3.7E+06	8.7E-01	1.2E+00	160040	2999.9	1.1E-06	1.3E-12	1.2E-13	6.2E-12	1.8E-12	1.1E-13	2.4E-13	1.7E-16	1.2E-16
2R1	29	27	3.7E+06	8.7E-01	1.2E+00	163040	4000.1	1.5E-06	1.5E-12	1.7E-13	9.0E-12	2.5E-12	1.2E-13	2.8E-13	2.1E-16	1.5E-16
2R1	30	27	3.7E+06	8.7E-01	1.2E+00	167040	4000	1.6E-06	1.4E-12	1.7E-13	9.4E-12	2.7E-12	9.5E-14	2.4E-13	1.9E-16	1.4E-16
2R1	31	27	3.7E+06	8.7E-01	1.2E+00	171040	1399.9	5.9E-07	4.3E-13	5.8E-14	3.3E-12	1.0E-12	2.9E-14	7.6E-14	6.1E-17	4.6E-17
2R1	32	27	3.7E+06	8.7E-01	1.2E+00	172440	4084	1.8E-06	1.1E-12	1.6E-13	9.5E-12	3.2E-12	7.3E-14	2.0E-13	1.6E-16	1.3E-16
2R1	33	27	3.7E+06	8.7E-01	1.2E+00	176520	3916.1	1.8E-06	1.2E-12	1.5E-13	9.3E-12	3.7E-12	5.9E-14	1.8E-13	1.5E-16	1.2E-16
2R1	34	820	3.0E+03	1.1E-03	6.0E-01	176520	23916	1.9E-04	1.1E-06	8.7E-08	2.8E-06	2.4E-06	2.3E-08	8.4E-08	9.9E-11	8.6E-11
2R1	35	821	2.5E+03	8.9E-04	6.0E-01	176520	23916	1.5E-04	9.1E-07	7.2E-08	2.3E-06	1.9E-06	1.9E-08	6.9E-08	8.2E-11	7.1E-11
2R1	36	824	1.4E+03	5.1E-04	6.0E-01	176520	23916	8.7E-05	5.2E-07	4.1E-08	1.3E-06	1.1E-06	1.1E-08	4.0E-08	4.7E-11	4.1E-11
2R1	37	27	3.7E+06	8.7E-01	1.2E+00	180440	3999.9	1.9E-06	1.5E-12	1.5E-13	9.8E-12	3.9E-12	5.2E-14	1.6E-13	1.5E-16	1.2E-16
2R1	38	27	3.7E+06	8.7E-01	1.2E+00	184440	4000.1	2.0E-06	1.6E-12	1.4E-13	1.0E-11	3.8E-12	4.5E-14	1.5E-13	1.5E-16	1.2E-16
2R1	39	27	3.7E+06	8.7E-01	1.2E+00	188440	3999.9	2.1E-06	1.6E-12	1.4E-13	1.0E-11	3.5E-12	3.9E-14	1.3E-13	1.5E-16	1.3E-16
2R1	40	27	3.7E+06	8.7E-01	1.2E+00	192440	4000.1	2.2E-06	1.5E-12	1.2E-13	1.0E-11	3.2E-12	3.3E-14	1.2E-13	1.5E-16	1.3E-16
2R1	41	27	3.7E+06	8.7E-01	1.2E+00	196440	4000	2.3E-06	1.4E-12	1.1E-13	1.0E-11	2.9E-12	2.9E-14	1.1E-13	1.5E-16	1.3E-16
2R1	42	27	3.7E+06	8.7E-01	1.2E+00	200440	3999.9	2.4E-06	1.3E-12	9.8E-14	1.0E-11	2.6E-12	2.4E-14	1.0E-13	1.4E-16	1.3E-16
2R1	43	820	3.3E+03	1.2E-03	5.8E-01	200440	20000	1.6E-04	6.0E-07	3.7E-08	1.9E-06	1.1E-06	8.2E-09	5.5E-08	7.8E-11	7.2E-11
2R1	44	821	2.7E+03	9.6E-04	5.8E-01	200440	20000	1.3E-04	5.0E-07	3.0E-08	1.5E-06	8.9E-07	6.8E-09	4.5E-08	6.4E-11	5.9E-11
2R1	45	824	1.5E+03	5.5E-04	5.8E-01	200440	20000	7.5E-05	2.8E-07	1.7E-08	8.8E-07	5.1E-07	3.9E-09	2.6E-08	3.7E-11	3.4E-11
2R1	46	27	3.6E+06	8.7E-01	1.2E+00	204440	4000.1	2.5E-06	1.2E-12	8.5E-14	1.0E-11	2.3E-12	2.0E-14	9.4E-14	1.4E-16	1.2E-16
2R1	47	27	3.6E+06	8.6E-01	1.2E+00	208440	3999.9	2.5E-06	1.1E-12	7.4E-14	1.0E-11	2.0E-12	1.7E-14	9.2E-14	1.3E-16	1.2E-16
2R1	48	27	3.7E+06	8.7E-01	1.2E+00	212440	4000.1	2.6E-06	1.0E-12	6.5E-14	1.0E-11	1.9E-12	1.5E-14	9.1E-14	1.3E-16	1.2E-16
2R1	49	27	3.7E+06	8.7E-01	1.2E+00	216440	4000	2.7E-06	9.6E-13	5.7E-14	1.1E-11	1.7E-12	1.3E-14	9.2E-14	1.3E-16	1.2E-16
2R1	50	27	3.7E+06	8.7E-01	1.2E+00	220440	3999.9	2.8E-06	9.0E-13	5.1E-14	1.1E-11	1.6E-12	1.1E-14	9.1E-14	1.2E-16	1.1E-16
2R1	51	820	3.5E+03	1.2E-03	5.6E-01	220440	23361	1.9E-04	5.0E-07	2.5E-08	1.8E-06	8.8E-07	4.6E-09	6.2E-08	7.9E-11	7.6E-11
2R1	52	821	2.9E+03	1.0E-03	5.6E-01	220440	23361	1.6E-04	4.1E-07	2.1E-08	1.5E-06	7.3E-07	3.8E-09	5.1E-08	6.5E-11	6.2E-11
2R1	53	824	1.6E+03	5.8E-04	5.6E-01	220440	23361	9.0E-05	2.4E-07	1.2E-08	8.5E-07	4.1E-07	2.2E-09	2.9E-08	3.7E-11	3.6E-11
2R1	54	27	3.7E+06	8.7E-01	1.2E+00	224440	4000.1	2.9E-06	8.5E-13	4.6E-14	1.1E-11	1.5E-12	9.8E-15	9.1E-14	1.2E-16	1.1E-16
2R1	55	27	3.7E+06	8.7E-01	1.2E+00	228440	4000	3.0E-06	8.1E-13	4.2E-14	1.1E-11	1.4E-12	8.6E-15	9.2E-14	1.2E-16	1.1E-16
2R1	56	27	3.7E+06	8.8E-01	1.2E+00	232440	4000	3.0E-06	7.7E-13	3.9E-14	1.1E-11	1.3E-12	7.6E-15	9.2E-14	1.2E-16	1.1E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	57	27	3.6E+06	8.6E-01	1.2E+00	236440	4000	3.1E-06	7.3E-13	3.6E-14	1.1E-11	1.3E-12	6.7E-15	9.0E-14	1.1E-16	1.1E-16
2R1	58	27	3.6E+06	8.6E-01	1.2E+00	240440	3360.9	2.6E-06	5.8E-13	2.9E-14	8.9E-12	1.0E-12	5.1E-15	7.3E-14	9.4E-17	9.1E-17
2R1	59	820	3.7E+03	1.3E-03	5.5E-01	243800	20639	1.7E-04	3.1E-07	1.5E-08	1.4E-06	6.6E-07	2.1E-09	3.8E-08	6.3E-11	6.2E-11
2R1	60	821	3.0E+03	1.1E-03	5.5E-01	243800	20639	1.4E-04	2.5E-07	1.3E-08	1.2E-06	5.5E-07	1.7E-09	3.1E-08	5.2E-11	5.1E-11
2R1	61	824	1.7E+03	6.1E-04	5.5E-01	243800	20639	8.2E-05	1.5E-07	7.3E-09	6.7E-07	3.1E-07	9.8E-10	1.8E-08	2.9E-11	2.9E-11
2R1	62	27	3.6E+06	8.6E-01	1.2E+00	244440	4000	3.2E-06	6.5E-13	3.2E-14	1.1E-11	1.2E-12	5.3E-15	8.2E-14	1.1E-16	1.1E-16
2R1	63	27	3.6E+06	8.6E-01	1.2E+00	248440	4000.1	3.3E-06	6.1E-13	3.0E-14	1.1E-11	1.2E-12	4.8E-15	7.6E-14	1.1E-16	1.1E-16
2R1	64	27	3.6E+06	8.6E-01	1.2E+00	252440	4000	3.3E-06	5.8E-13	2.9E-14	1.1E-11	1.2E-12	4.3E-15	7.1E-14	1.1E-16	1.1E-16
2R1	65	27	3.6E+06	8.6E-01	1.2E+00	256440	3999.9	3.4E-06	5.5E-13	2.8E-14	1.1E-11	1.2E-12	3.8E-15	6.7E-14	1.1E-16	1.1E-16
2R1	66	27	3.6E+06	8.6E-01	1.2E+00	260440	4000.1	3.5E-06	5.2E-13	2.6E-14	1.1E-11	1.2E-12	3.5E-15	6.4E-14	1.1E-16	1.1E-16
2R1	67	27	3.6E+06	8.6E-01	1.2E+00	264440	4000	3.5E-06	5.0E-13	2.5E-14	1.1E-11	1.2E-12	3.1E-15	6.1E-14	1.1E-16	1.1E-16
2R1	68	820	3.9E+03	1.3E-03	5.4E-01	264440	20000	1.7E-04	2.3E-07	1.1E-08	1.3E-06	6.3E-07	1.2E-09	2.5E-08	5.6E-11	5.6E-11
2R1	69	821	3.2E+03	1.1E-03	5.4E-01	264440	20000	1.4E-04	1.9E-07	9.3E-09	1.1E-06	5.2E-07	9.6E-10	2.1E-08	4.7E-11	4.6E-11
2R1	70	824	1.8E+03	6.3E-04	5.4E-01	264440	20000	8.1E-05	1.1E-07	5.3E-09	6.1E-07	3.0E-07	5.5E-10	1.2E-08	2.7E-11	2.7E-11
2R1	71	27	3.6E+06	8.6E-01	1.2E+00	268440	4000	3.6E-06	4.8E-13	2.4E-14	1.1E-11	1.2E-12	2.8E-15	5.7E-14	1.1E-16	1.1E-16
2R1	72	27	3.6E+06	8.6E-01	1.2E+00	272440	4000	3.7E-06	4.6E-13	2.3E-14	1.1E-11	1.2E-12	2.6E-15	5.3E-14	1.1E-16	1.0E-16
2R1	73	27	3.6E+06	8.6E-01	1.2E+00	276440	3999.9	3.7E-06	4.5E-13	2.2E-14	1.1E-11	1.2E-12	2.3E-15	4.9E-14	1.0E-16	1.0E-16
2R1	74	27	3.6E+06	8.6E-01	1.2E+00	280440	4000	3.8E-06	4.3E-13	2.1E-14	1.1E-11	1.2E-12	2.1E-15	4.5E-14	1.0E-16	1.0E-16
2R1	75	27	3.6E+06	8.6E-01	1.2E+00	284440	4000	3.8E-06	4.2E-13	2.0E-14	1.1E-11	1.2E-12	1.9E-15	4.2E-14	1.0E-16	1.0E-16
2R1	76	820	4.0E+03	1.4E-03	5.2E-01	284440	24000	2.1E-04	2.2E-07	1.1E-08	1.4E-06	8.1E-07	8.0E-10	1.8E-08	6.3E-11	6.4E-11
2R1	77	821	3.3E+03	1.1E-03	5.2E-01	284440	24000	1.7E-04	1.8E-07	8.7E-09	1.2E-06	6.7E-07	6.6E-10	1.5E-08	5.2E-11	5.2E-11
2R1	78	824	1.9E+03	6.5E-04	5.2E-01	284440	24000	9.9E-05	1.0E-07	5.0E-09	6.8E-07	3.8E-07	3.8E-10	8.6E-09	3.0E-11	3.0E-11
2R1	79	27	3.6E+06	8.6E-01	1.2E+00	288440	4000	3.9E-06	4.0E-13	1.9E-14	1.1E-11	1.2E-12	1.7E-15	3.8E-14	1.0E-16	1.0E-16
2R1	80	27	3.6E+06	8.6E-01	1.2E+00	292440	4000.1	4.0E-06	3.9E-13	1.8E-14	1.1E-11	1.2E-12	1.6E-15	3.5E-14	1.0E-16	1.0E-16
2R1	81	27	3.6E+06	8.6E-01	1.2E+00	296440	4000	4.0E-06	3.7E-13	1.8E-14	1.1E-11	1.3E-12	1.4E-15	3.3E-14	1.0E-16	1.0E-16
2R1	82	27	3.6E+06	8.6E-01	1.2E+00	300440	4000.1	4.1E-06	3.6E-13	1.7E-14	1.1E-11	1.3E-12	1.3E-15	3.0E-14	1.0E-16	1.0E-16
2R1	83	27	3.6E+06	8.6E-01	1.2E+00	304440	3999.9	4.1E-06	3.4E-13	1.7E-14	1.1E-11	1.3E-12	1.2E-15	2.8E-14	1.0E-16	1.0E-16
2R1	84	27	3.6E+06	8.6E-01	1.2E+00	308440	4000.1	4.2E-06	3.3E-13	1.6E-14	1.1E-11	1.4E-12	1.1E-15	2.6E-14	9.9E-17	1.0E-16
2R1	85	820	4.2E+03	1.4E-03	5.1E-01	308440	20000	1.8E-04	1.4E-07	7.6E-09	1.0E-06	8.1E-07	3.9E-10	9.5E-09	4.9E-11	5.0E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	86	821	3.4E+03	1.2E-03	5.1E-01	308440	20000	1.5E-04	1.1E-07	6.2E-09	8.6E-07	6.7E-07	3.2E-10	7.9E-09	4.1E-11	4.1E-11
2R1	87	824	2.0E+03	6.7E-04	5.1E-01	308440	20000	8.3E-05	6.6E-08	3.6E-09	4.9E-07	3.8E-07	1.9E-10	4.5E-09	2.3E-11	2.4E-11
2R1	88	27	3.6E+06	8.6E-01	1.2E+00	312440	3999.9	4.2E-06	3.1E-13	1.6E-14	1.1E-11	1.4E-12	1.0E-15	2.4E-14	9.9E-17	1.0E-16
2R1	89	27	3.6E+06	8.6E-01	1.2E+00	316440	4000	4.3E-06	3.0E-13	1.5E-14	1.1E-11	1.5E-12	9.2E-16	2.2E-14	9.8E-17	9.9E-17
2R1	90	27	3.6E+06	8.6E-01	1.2E+00	320440	4000.1	4.3E-06	2.9E-13	1.5E-14	1.1E-11	1.5E-12	8.4E-16	2.0E-14	9.7E-17	9.9E-17
2R1	91	27	3.6E+06	8.6E-01	1.2E+00	324440	3999.9	4.4E-06	2.7E-13	1.5E-14	1.1E-11	1.6E-12	7.7E-16	1.9E-14	9.7E-17	9.8E-17
2R1	92	27	3.6E+06	8.6E-01	1.2E+00	328440	4000	4.4E-06	2.6E-13	1.5E-14	1.1E-11	1.7E-12	7.1E-16	1.7E-14	9.6E-17	9.8E-17
2R1	93	820	4.3E+03	1.5E-03	5.0E-01	328440	24000	2.2E-04	1.3E-07	8.7E-09	1.1E-06	1.3E-06	2.9E-10	7.4E-09	5.6E-11	5.7E-11
2R1	94	821	3.5E+03	1.2E-03	5.0E-01	328440	24000	1.8E-04	1.1E-07	7.2E-09	8.8E-07	1.1E-06	2.4E-10	6.1E-09	4.6E-11	4.7E-11
2R1	95	824	2.0E+03	6.9E-04	5.0E-01	328440	24000	1.0E-04	6.0E-08	4.1E-09	5.0E-07	6.1E-07	1.4E-10	3.5E-09	2.6E-11	2.7E-11
2R1	96	27	3.6E+06	8.6E-01	1.2E+00	332440	4000.1	4.5E-06	2.5E-13	1.5E-14	1.1E-11	1.8E-12	6.5E-16	1.6E-14	9.6E-17	9.8E-17
2R1	97	27	3.6E+06	8.6E-01	1.2E+00	336440	4000.1	4.5E-06	2.4E-13	1.5E-14	1.1E-11	1.9E-12	6.0E-16	1.5E-14	9.5E-17	9.7E-17
2R1	98	27	3.6E+06	8.6E-01	1.2E+00	340440	3999.9	4.6E-06	2.3E-13	1.5E-14	1.1E-11	2.0E-12	5.5E-16	1.4E-14	9.5E-17	9.7E-17
2R1	99	27	3.6E+06	8.6E-01	1.2E+00	344440	4000	4.6E-06	2.2E-13	1.5E-14	1.1E-11	2.1E-12	5.1E-16	1.3E-14	9.5E-17	9.7E-17
2R1	100	27	3.6E+06	8.6E-01	1.2E+00	348440	3999.9	4.6E-06	2.1E-13	1.5E-14	1.1E-11	2.3E-12	4.7E-16	1.2E-14	9.5E-17	9.7E-17
2R1	101	27	3.6E+06	8.6E-01	1.2E+00	352440	4000	4.7E-06	2.0E-13	1.5E-14	1.1E-11	2.5E-12	4.3E-16	1.1E-14	9.5E-17	9.7E-17
2R1	102	820	4.4E+03	1.5E-03	5.0E-01	352440	20000	1.8E-04	8.2E-08	9.1E-09	7.4E-07	1.9E-06	1.5E-10	5.0E-09	4.7E-11	4.8E-11
2R1	103	821	3.6E+03	1.2E-03	5.0E-01	352440	20000	1.5E-04	6.8E-08	7.5E-09	6.1E-07	1.5E-06	1.2E-10	4.1E-09	3.9E-11	4.0E-11
2R1	104	824	2.1E+03	7.1E-04	5.0E-01	352440	20000	8.5E-05	3.9E-08	4.3E-09	3.5E-07	8.8E-07	7.1E-11	2.3E-09	2.2E-11	2.3E-11
2R1	105	27	3.6E+06	8.6E-01	1.2E+00	356440	4000.2	4.7E-06	1.9E-13	1.6E-14	1.1E-11	2.7E-12	4.0E-16	1.0E-14	9.5E-17	9.7E-17
2R1	106	27	3.6E+06	8.6E-01	1.2E+00	360440	3999.9	4.8E-06	1.8E-13	1.7E-14	1.1E-11	3.0E-12	3.7E-16	9.8E-15	9.5E-17	9.8E-17
2R1	107	27	3.6E+06	8.6E-01	1.2E+00	364440	4000	4.8E-06	1.8E-13	1.8E-14	1.1E-11	3.4E-12	3.4E-16	9.7E-15	9.6E-17	9.9E-17
2R1	108	27	3.6E+06	8.6E-01	1.2E+00	368440	3999.8	4.9E-06	1.7E-13	1.9E-14	1.1E-11	4.0E-12	3.1E-16	1.0E-14	9.8E-17	1.0E-16
2R1	109	27	3.6E+06	8.6E-01	1.2E+00	372440	4000	4.9E-06	1.6E-13	2.1E-14	1.1E-11	4.9E-12	2.9E-16	1.8E-14	1.0E-16	1.0E-16
2R1	110	820	4.5E+03	1.5E-03	4.9E-01	372440	20000	1.8E-04	5.3E-08	1.1E-08	4.2E-07	3.8E-06	6.5E-11	4.7E-05	3.5E-11	3.6E-11
2R1	111	821	3.7E+03	1.3E-03	4.9E-01	372440	20000	1.5E-04	4.3E-08	8.8E-09	3.5E-07	3.1E-06	5.4E-11	3.9E-05	2.9E-11	3.0E-11
2R1	112	824	2.1E+03	7.2E-04	4.9E-01	372440	20000	8.6E-05	2.5E-08	5.0E-09	2.0E-07	1.8E-06	3.1E-11	2.2E-05	1.7E-11	1.7E-11
2R1	113	27	3.6E+06	8.6E-01	1.2E+00	376440	4000.2	4.9E-06	1.1E-13	1.6E-14	1.1E-11	4.8E-12	1.9E-16	3.4E-11	7.0E-17	7.2E-17
2R1	114	27	3.6E+06	8.6E-01	1.2E+00	380440	3999.8	5.0E-06	6.3E-14	1.1E-14	1.0E-11	4.3E-12	9.8E-17	5.6E-11	4.2E-17	4.3E-17

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	115	27	3.6E+06	8.6E-01	1.2E+00	384440	4000.1	5.0E-06	5.1E-14	1.0E-14	1.0E-11	3.9E-12	6.3E-17	5.1E-11	3.4E-17	3.5E-17
2R1	116	27	3.6E+06	8.6E-01	1.2E+00	388440	4000.1	5.0E-06	4.9E-14	1.1E-14	1.0E-11	3.3E-12	4.9E-17	4.3E-11	3.1E-17	3.2E-17
2R1	117	27	3.6E+06	8.6E-01	1.2E+00	392440	3999.9	5.1E-06	5.4E-14	1.2E-14	1.0E-11	2.8E-12	3.6E-17	3.5E-11	3.1E-17	3.2E-17
2R1	118	820	4.6E+03	1.6E-03	4.9E-01	392440	24000	2.2E-04	8.4E-08	1.7E-08	2.2E-07	1.4E-06	1.6E-11	1.7E-05	3.6E-11	3.6E-11
2R1	119	821	3.8E+03	1.3E-03	4.9E-01	392440	24000	1.8E-04	6.9E-08	1.4E-08	1.8E-07	1.2E-06	1.4E-11	1.4E-05	2.9E-11	3.0E-11
2R1	120	824	2.2E+03	7.4E-04	4.9E-01	392440	24000	1.0E-04	3.9E-08	8.0E-09	1.0E-07	6.6E-07	7.7E-12	8.0E-06	1.7E-11	1.7E-11
2R1	121	27	3.6E+06	8.6E-01	1.2E+00	396440	4000.1	5.1E-06	6.1E-14	1.4E-14	1.0E-11	2.4E-12	2.9E-17	2.9E-11	3.2E-17	3.3E-17
2R1	122	27	3.6E+06	8.6E-01	1.2E+00	400440	4000	5.1E-06	7.2E-14	1.6E-14	1.0E-11	2.0E-12	2.3E-17	2.4E-11	3.5E-17	3.6E-17
2R1	123	27	3.6E+06	8.6E-01	1.2E+00	404440	3999.9	5.2E-06	8.5E-14	1.8E-14	1.0E-11	1.7E-12	2.1E-17	2.1E-11	3.8E-17	3.9E-17
2R1	124	27	3.6E+06	8.6E-01	1.2E+00	408440	4000	5.2E-06	9.9E-14	2.0E-14	1.0E-11	1.5E-12	1.9E-17	1.8E-11	4.2E-17	4.2E-17
2R1	125	27	3.6E+06	8.6E-01	1.2E+00	412440	4000	5.2E-06	1.2E-13	2.2E-14	1.0E-11	1.4E-12	1.6E-17	1.6E-11	4.6E-17	4.6E-17
2R1	126	27	3.6E+06	8.6E-01	1.2E+00	416440	4000	5.3E-06	1.3E-13	2.5E-14	1.0E-11	1.2E-12	1.7E-17	1.4E-11	5.0E-17	5.1E-17
2R1	127	820	4.8E+03	1.6E-03	4.9E-01	416440	20000	1.8E-04	1.2E-07	2.1E-08	1.7E-07	5.1E-07	7.7E-12	6.0E-06	4.1E-11	4.1E-11
2R1	128	821	3.9E+03	1.3E-03	4.9E-01	416440	20000	1.5E-04	9.7E-08	1.7E-08	1.4E-07	4.2E-07	6.4E-12	4.9E-06	3.4E-11	3.4E-11
2R1	129	824	2.2E+03	7.6E-04	4.9E-01	416440	20000	8.7E-05	5.5E-08	9.9E-09	8.1E-08	2.4E-07	3.6E-12	2.8E-06	1.9E-11	1.9E-11
2R1	130	27	3.6E+06	8.6E-01	1.2E+00	420440	3999.9	5.3E-06	1.5E-13	2.8E-14	1.0E-11	1.1E-12	1.3E-17	1.3E-11	5.5E-17	5.6E-17
2R1	131	27	3.6E+06	8.6E-01	1.2E+00	424440	4000.2	5.3E-06	1.7E-13	3.1E-14	1.0E-11	1.0E-12	1.5E-17	1.2E-11	6.1E-17	6.2E-17
2R1	132	27	3.6E+06	8.6E-01	1.2E+00	428440	3999.9	5.4E-06	1.9E-13	3.4E-14	1.0E-11	9.3E-13	1.4E-17	1.1E-11	6.7E-17	6.8E-17
2R1	133	27	3.6E+06	8.6E-01	1.2E+00	432440	3999.9	5.4E-06	2.1E-13	3.8E-14	1.0E-11	8.6E-13	1.3E-17	1.0E-11	7.3E-17	7.4E-17
2R1	134	27	3.6E+06	8.6E-01	1.2E+00	436440	4000.2	5.4E-06	2.3E-13	4.0E-14	1.0E-11	7.9E-13	1.2E-17	9.3E-12	7.8E-17	7.9E-17
2R1	135	820	4.8E+03	1.6E-03	4.8E-01	436440	24000	2.2E-04	1.9E-07	3.0E-08	2.1E-07	3.5E-07	7.0E-12	4.1E-06	5.8E-11	5.9E-11
2R1	136	821	4.0E+03	1.4E-03	4.8E-01	436440	24000	1.8E-04	1.5E-07	2.5E-08	1.8E-07	2.9E-07	5.9E-12	3.4E-06	4.8E-11	4.9E-11
2R1	137	824	2.3E+03	7.7E-04	4.8E-01	436440	24000	1.0E-04	8.8E-08	1.4E-08	1.0E-07	1.6E-07	3.4E-12	1.9E-06	2.7E-11	2.8E-11
2R1	138	27	3.6E+06	8.6E-01	1.2E+00	440440	3999.9	5.4E-06	2.5E-13	4.2E-14	1.0E-11	7.4E-13	1.3E-17	8.6E-12	8.2E-17	8.3E-17
2R1	139	27	3.6E+06	8.6E-01	1.2E+00	444440	4000	5.5E-06	2.7E-13	4.5E-14	1.1E-11	6.8E-13	1.2E-17	8.0E-12	8.7E-17	8.8E-17
2R1	140	27	3.6E+06	8.6E-01	1.2E+00	448440	4000	5.5E-06	2.8E-13	4.7E-14	1.1E-11	6.3E-13	1.3E-17	7.4E-12	9.0E-17	9.2E-17
2R1	141	27	3.6E+06	8.6E-01	1.2E+00	452440	4000.1	5.5E-06	3.0E-13	4.8E-14	1.1E-11	5.8E-13	1.0E-17	6.9E-12	9.3E-17	9.5E-17
2R1	142	27	3.6E+06	8.6E-01	1.2E+00	456440	3999.9	5.5E-06	3.1E-13	5.0E-14	1.1E-11	5.4E-13	1.0E-17	6.4E-12	9.7E-17	9.9E-17
2R1	143	27	3.6E+06	8.6E-01	1.2E+00	460440	4000	5.6E-06	3.3E-13	5.2E-14	1.1E-11	5.0E-13	1.4E-17	5.9E-12	1.0E-16	1.0E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	144	820	4.9E+03	1.7E-03	4.8E-01	460440	20000	1.9E-04	1.7E-07	2.9E-08	1.8E-07	1.8E-07	5.2E-12	2.1E-06	5.5E-11	5.6E-11
2R1	145	821	4.1E+03	1.4E-03	4.8E-01	460440	20000	1.5E-04	1.4E-07	2.4E-08	1.5E-07	1.5E-07	4.2E-12	1.7E-06	4.6E-11	4.6E-11
2R1	146	824	2.3E+03	7.8E-04	4.8E-01	460440	20000	8.8E-05	8.2E-08	1.4E-08	8.3E-08	8.4E-08	2.5E-12	9.9E-07	2.6E-11	2.6E-11
2R1	147	27	3.6E+06	8.6E-01	1.2E+00	464440	4000.1	5.6E-06	3.4E-13	5.4E-14	1.1E-11	4.6E-13	1.0E-17	5.5E-12	1.0E-16	1.1E-16
2R1	148	27	3.6E+06	8.6E-01	1.2E+00	468440	4000	5.6E-06	3.5E-13	5.6E-14	1.1E-11	4.3E-13	1.1E-17	5.1E-12	1.1E-16	1.1E-16
2R1	149	27	3.6E+06	8.6E-01	1.2E+00	472440	4000	5.6E-06	3.5E-13	5.8E-14	1.1E-11	4.0E-13	1.0E-17	4.7E-12	1.1E-16	1.1E-16
2R1	150	27	3.6E+06	8.6E-01	1.2E+00	476440	4000	5.7E-06	3.6E-13	6.0E-14	1.1E-11	3.7E-13	1.0E-17	4.4E-12	1.1E-16	1.2E-16
2R1	151	27	3.6E+06	8.6E-01	1.2E+00	480440	3999.9	5.7E-06	3.7E-13	6.2E-14	1.1E-11	3.4E-13	1.1E-17	4.0E-12	1.2E-16	1.2E-16
2R1	152	820	5.0E+03	1.7E-03	4.8E-01	480440	20000	1.9E-04	1.8E-07	3.2E-08	1.7E-07	1.2E-07	5.1E-12	1.4E-06	6.1E-11	6.2E-11
2R1	153	821	4.1E+03	1.4E-03	4.8E-01	480440	20000	1.5E-04	1.5E-07	2.7E-08	1.4E-07	9.9E-08	4.2E-12	1.2E-06	5.0E-11	5.1E-11
2R1	154	824	2.3E+03	7.9E-04	4.8E-01	480440	20000	8.8E-05	8.4E-08	1.5E-08	8.0E-08	5.6E-08	2.3E-12	6.6E-07	2.9E-11	2.9E-11
2R1	155	27	3.6E+06	8.6E-01	1.2E+00	484440	3999.9	5.7E-06	3.7E-13	6.4E-14	1.1E-11	3.2E-13	1.0E-17	3.8E-12	1.2E-16	1.2E-16
2R1	156	27	3.6E+06	8.6E-01	1.2E+00	488440	4000.1	5.7E-06	3.7E-13	6.5E-14	1.1E-11	3.0E-13	1.1E-17	3.5E-12	1.2E-16	1.3E-16
2R1	157	27	3.6E+06	8.6E-01	1.2E+00	492440	4000	5.7E-06	3.7E-13	6.7E-14	1.1E-11	2.7E-13	1.0E-17	3.2E-12	1.3E-16	1.3E-16
2R1	158	27	3.6E+06	8.6E-01	1.2E+00	496440	4000	5.8E-06	3.8E-13	6.8E-14	1.1E-11	2.5E-13	1.0E-17	3.0E-12	1.3E-16	1.3E-16
2R1	159	27	3.6E+06	8.6E-01	1.2E+00	500440	4000	5.8E-06	3.8E-13	6.9E-14	1.1E-11	2.4E-13	1.1E-17	2.8E-12	1.3E-16	1.3E-16
2R1	160	820	5.0E+03	1.7E-03	4.8E-01	500440	24000	2.2E-04	2.1E-07	4.0E-08	1.9E-07	9.4E-08	5.7E-12	1.1E-06	7.6E-11	7.7E-11
2R1	161	821	4.1E+03	1.4E-03	4.8E-01	500440	24000	1.8E-04	1.7E-07	3.3E-08	1.6E-07	7.8E-08	4.8E-12	9.2E-07	6.3E-11	6.4E-11
2R1	162	824	2.4E+03	7.9E-04	4.8E-01	500440	24000	1.1E-04	9.7E-08	1.9E-08	9.0E-08	4.4E-08	2.6E-12	5.2E-07	3.6E-11	3.6E-11
2R1	163	27	3.6E+06	8.6E-01	1.2E+00	504440	4000	5.8E-06	3.7E-13	7.0E-14	1.1E-11	2.2E-13	1.0E-17	2.6E-12	1.3E-16	1.3E-16
2R1	164	27	3.6E+06	8.6E-01	1.2E+00	508440	4098.8	6.0E-06	3.8E-13	7.3E-14	1.1E-11	2.1E-13	1.0E-17	2.5E-12	1.4E-16	1.4E-16
2R1	165	27	3.6E+06	8.6E-01	1.2E+00	512540	3901.3	5.7E-06	3.6E-13	7.0E-14	1.1E-11	1.8E-13	1.0E-17	2.2E-12	1.3E-16	1.3E-16
2R1	166	27	3.6E+06	8.6E-01	1.2E+00	516440	3999.9	5.8E-06	3.7E-13	7.1E-14	1.1E-11	1.7E-13	9.5E-18	2.1E-12	1.3E-16	1.4E-16
2R1	167	27	3.6E+06	8.6E-01	1.2E+00	520440	4000	5.9E-06	3.6E-13	7.1E-14	1.1E-11	1.6E-13	1.0E-17	1.9E-12	1.3E-16	1.4E-16
2R1	168	27	3.6E+06	8.6E-01	1.2E+00	524440	4000	5.9E-06	3.6E-13	7.0E-14	1.1E-11	1.5E-13	9.5E-18	1.8E-12	1.3E-16	1.4E-16
2R1	169	820	5.1E+03	1.7E-03	4.8E-01	524440	20000	1.9E-04	1.6E-07	3.1E-08	1.5E-07	5.1E-08	3.9E-12	6.1E-07	6.0E-11	6.1E-11
2R1	170	821	4.2E+03	1.4E-03	4.8E-01	524440	20000	1.5E-04	1.3E-07	2.6E-08	1.3E-07	4.2E-08	3.2E-12	5.1E-07	5.0E-11	5.0E-11
2R1	171	824	2.4E+03	8.0E-04	4.8E-01	524440	20000	8.8E-05	7.6E-08	1.5E-08	7.2E-08	2.4E-08	1.9E-12	2.9E-07	2.8E-11	2.9E-11
2R1	172	27	3.6E+06	8.6E-01	1.2E+00	528440	4000	5.9E-06	3.5E-13	6.9E-14	1.1E-11	1.4E-13	8.7E-18	1.6E-12	1.3E-16	1.3E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R1	173	27	3.6E+06	8.6E-01	1.2E+00	532440	4000	5.9E-06	3.5E-13	6.7E-14	1.1E-11	1.3E-13	9.5E-18	1.5E-12	1.3E-16	1.3E-16
2R1	174	27	3.6E+06	8.6E-01	1.2E+00	536440	4000	5.9E-06	3.4E-13	6.6E-14	1.1E-11	1.2E-13	7.8E-18	1.4E-12	1.3E-16	1.3E-16
2R1	175	27	3.6E+06	8.6E-01	1.2E+00	540440	4000	5.9E-06	3.4E-13	6.5E-14	1.1E-11	1.1E-13	8.7E-18	1.3E-12	1.3E-16	1.3E-16
2R1	176	27	3.6E+06	8.6E-01	1.2E+00	544440	4000.1	6.0E-06	3.3E-13	6.4E-14	1.1E-11	1.0E-13	7.8E-18	1.2E-12	1.2E-16	1.3E-16
2R1	177	820	5.1E+03	1.7E-03	4.8E-01	544440	24000	2.3E-04	1.8E-07	3.5E-08	1.7E-07	4.1E-08	4.1E-12	4.9E-07	6.8E-11	6.9E-11
2R1	178	821	4.2E+03	1.4E-03	4.8E-01	544440	24000	1.9E-04	1.5E-07	2.9E-08	1.4E-07	3.3E-08	3.3E-12	4.1E-07	5.6E-11	5.7E-11
2R1	179	824	2.4E+03	8.1E-04	4.8E-01	544440	24000	1.1E-04	8.3E-08	1.6E-08	8.1E-08	1.9E-08	1.9E-12	2.3E-07	3.2E-11	3.3E-11
2R1	180	27	3.6E+06	8.6E-01	1.2E+00	548440	3999.9	6.0E-06	3.3E-13	6.3E-14	1.1E-11	9.2E-14	7.8E-18	1.1E-12	1.2E-16	1.3E-16
2R1	181	27	3.6E+06	8.6E-01	1.2E+00	552440	3999.9	6.0E-06	3.2E-13	6.3E-14	1.1E-11	8.6E-14	6.9E-18	1.0E-12	1.2E-16	1.2E-16
2R1	182	27	3.6E+06	8.6E-01	1.2E+00	556440	4000.1	6.0E-06	3.2E-13	6.2E-14	1.1E-11	7.9E-14	7.8E-18	9.6E-13	1.2E-16	1.2E-16
2R1	183	27	3.6E+06	8.6E-01	1.2E+00	560440	3999.9	6.0E-06	3.1E-13	6.1E-14	1.1E-11	7.4E-14	6.9E-18	9.0E-13	1.2E-16	1.2E-16
2R1	184	27	3.6E+06	8.6E-01	1.2E+00	564440	4000.1	6.0E-06	3.1E-13	6.0E-14	1.1E-11	6.9E-14	6.9E-18	8.4E-13	1.2E-16	1.2E-16
2R1	185	27	3.6E+06	8.6E-01	1.2E+00	568440	4000	6.0E-06	3.0E-13	6.0E-14	1.1E-11	6.4E-14	6.9E-18	7.8E-13	1.2E-16	1.2E-16
2R1	186	820	5.2E+03	1.7E-03	4.7E-01	568440	20000	1.9E-04	1.3E-07	2.7E-08	1.3E-07	2.2E-08	2.8E-12	2.8E-07	5.4E-11	5.5E-11
2R1	187	821	4.3E+03	1.4E-03	4.7E-01	568440	20000	1.6E-04	1.1E-07	2.2E-08	1.1E-07	1.8E-08	2.4E-12	2.3E-07	4.4E-11	4.5E-11
2R1	188	824	2.4E+03	8.1E-04	4.7E-01	568440	20000	8.9E-05	6.2E-08	1.3E-08	6.3E-08	1.1E-08	1.4E-12	1.3E-07	2.5E-11	2.6E-11
2R1	189	27	3.6E+06	8.6E-01	1.2E+00	572440	4000.1	6.0E-06	3.0E-13	5.9E-14	1.1E-11	5.9E-14	6.1E-18	7.3E-13	1.2E-16	1.2E-16
2R1	190	27	3.6E+06	8.6E-01	1.2E+00	576440	4000	6.1E-06	2.9E-13	5.9E-14	1.1E-11	5.5E-14	6.9E-18	6.8E-13	1.2E-16	1.2E-16
2R1	191	27	3.6E+06	8.6E-01	1.2E+00	580440	3999.9	6.1E-06	2.9E-13	5.8E-14	1.1E-11	5.1E-14	6.1E-18	6.4E-13	1.2E-16	1.2E-16
2R1	192	27	3.6E+06	8.6E-01	1.2E+00	584440	4000	6.1E-06	2.8E-13	5.8E-14	1.1E-11	4.8E-14	6.1E-18	6.0E-13	1.1E-16	1.2E-16
2R1	193	27	3.6E+06	8.6E-01	1.2E+00	588440	4000.1	6.1E-06	2.8E-13	5.7E-14	1.1E-11	4.5E-14	6.1E-18	5.6E-13	1.1E-16	1.2E-16
2R1	194	820	5.2E+03	1.7E-03	4.7E-01	588440	16000	1.5E-04	9.6E-08	2.1E-08	1.0E-07	1.3E-08	2.0E-12	1.6E-07	4.2E-11	4.2E-11
2R1	195	821	4.3E+03	1.4E-03	4.7E-01	588440	16000	1.2E-04	7.9E-08	1.7E-08	8.5E-08	1.1E-08	1.6E-12	1.4E-07	3.5E-11	3.5E-11
2R1	196	824	2.5E+03	8.2E-04	4.7E-01	588440	16000	7.1E-05	4.5E-08	9.8E-09	4.8E-08	6.1E-09	1.0E-12	7.7E-08	2.0E-11	2.0E-11
2R1	197	27	3.6E+06	8.6E-01	1.2E+00	592440	3999.9	6.1E-06	2.7E-13	5.6E-14	1.1E-11	4.2E-14	6.1E-18	5.2E-13	1.1E-16	1.1E-16
2R1	198	27	3.6E+06	8.6E-01	1.2E+00	596440	4000.1	6.1E-06	2.7E-13	5.6E-14	1.1E-11	3.9E-14	6.1E-18	4.9E-13	1.1E-16	1.1E-16
2R1	199	27	3.6E+06	8.6E-01	1.2E+00	600440	3999.8	6.1E-06	2.6E-13	5.7E-14	1.1E-11	3.6E-14	5.2E-18	4.6E-13	1.1E-16	1.2E-16
2R2	1	820	1.8E+03	4.5E-04	8.8E-01	48140	21600	1.9E-05	1.7E-06	5.1E-08	1.8E-06	1.7E-06	1.5E-08	3.8E-07	3.7E-13	3.7E-13
2R2	2	821	1.5E+03	3.7E-04	8.8E-01	48140	21600	1.5E-05	1.4E-06	4.2E-08	1.5E-06	1.4E-06	1.2E-08	3.1E-07	3.1E-13	3.1E-13

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R2	3	824	8.5E+02	2.1E-04	8.8E-01	48140	21600	8.8E-06	7.9E-07	2.4E-08	8.4E-07	8.1E-07	6.9E-09	1.8E-07	1.7E-13	1.7E-13
2R2	4	820	2.7E+03	7.3E-04	7.5E-01	69740	21300	1.1E-04	1.7E-05	2.2E-07	1.3E-05	1.0E-05	6.0E-08	3.6E-06	1.0E-10	1.5E-11
2R2	5	821	2.2E+03	6.0E-04	7.5E-01	69740	21300	9.0E-05	1.4E-05	1.8E-07	1.1E-05	8.6E-06	4.9E-08	3.1E-06	8.6E-11	1.2E-11
2R2	6	824	1.3E+03	3.4E-04	7.5E-01	69740	21300	5.2E-05	8.0E-06	1.0E-07	6.0E-06	4.9E-06	2.8E-08	1.8E-06	4.9E-11	7.1E-12
2R2	7	820	3.2E+03	9.0E-04	7.1E-01	91040	22000	1.5E-04	3.4E-07	7.7E-09	1.3E-06	3.1E-07	3.3E-10	3.1E-08	6.7E-11	2.1E-11
2R2	8	821	2.6E+03	7.4E-04	7.1E-01	91040	22000	1.3E-04	2.8E-07	6.4E-09	1.1E-06	2.6E-07	2.8E-10	2.6E-08	5.6E-11	1.7E-11
2R2	9	824	1.5E+03	4.2E-04	7.1E-01	91040	22000	7.1E-05	1.6E-07	3.6E-09	6.3E-07	1.5E-07	1.6E-10	1.5E-08	3.2E-11	9.8E-12
2R2	10	820	3.1E+03	1.1E-03	6.6E-01	113040	22000	1.6E-04	2.0E-07	3.8E-08	1.4E-06	4.4E-07	3.5E-10	2.1E-08	3.7E-11	3.1E-11
2R2	11	821	2.6E+03	8.9E-04	6.6E-01	113040	22000	1.4E-04	1.7E-07	3.1E-08	1.1E-06	3.6E-07	2.9E-10	1.8E-08	3.1E-11	2.6E-11
2R2	12	824	1.5E+03	5.1E-04	6.6E-01	113040	22000	7.8E-05	9.5E-08	1.8E-08	6.5E-07	2.1E-07	1.7E-10	1.0E-08	1.8E-11	1.5E-11
2R2	13	820	2.9E+03	1.1E-03	6.7E-01	135040	21000	1.6E-04	1.1E-07	1.3E-08	8.4E-07	4.3E-07	5.8E-11	4.4E-09	3.2E-11	3.0E-11
2R2	14	821	2.4E+03	9.0E-04	6.7E-01	135040	21000	1.3E-04	9.2E-08	1.1E-08	6.9E-07	3.6E-07	4.8E-11	3.7E-09	2.6E-11	2.4E-11
2R2	15	824	1.4E+03	5.1E-04	6.7E-01	135040	21000	7.5E-05	5.3E-08	6.0E-09	4.0E-07	2.0E-07	2.7E-11	2.1E-09	1.5E-11	1.4E-11
2R2	16	820	2.9E+03	1.1E-03	6.7E-01	156040	20400	1.6E-04	1.1E-07	3.1E-09	6.2E-07	4.7E-07	7.8E-12	2.0E-09	2.7E-11	2.6E-11
2R2	17	821	2.4E+03	9.1E-04	6.7E-01	156040	20400	1.3E-04	9.4E-08	2.6E-09	5.1E-07	3.9E-07	6.5E-12	1.7E-09	2.2E-11	2.1E-11
2R2	18	824	1.4E+03	5.2E-04	6.7E-01	156040	20400	7.5E-05	5.3E-08	1.5E-09	2.9E-07	2.2E-07	3.7E-12	9.5E-10	1.3E-11	1.2E-11
2R2	19	820	3.2E+03	1.2E-03	6.5E-01	176440	24000	1.9E-04	1.8E-07	3.0E-09	6.8E-07	7.7E-07	1.9E-12	2.4E-09	3.3E-11	3.2E-11
2R2	20	821	2.6E+03	9.8E-04	6.5E-01	176440	24000	1.6E-04	1.5E-07	2.5E-09	5.6E-07	6.4E-07	1.6E-12	2.0E-09	2.7E-11	2.7E-11
2R2	21	824	1.5E+03	5.6E-04	6.5E-01	176440	24000	9.2E-05	8.4E-08	1.4E-09	3.2E-07	3.6E-07	8.9E-13	1.2E-09	1.5E-11	1.5E-11
2R2	22	820	3.8E+03	1.4E-03	6.1E-01	200440	20000	1.7E-04	2.5E-07	4.7E-09	8.1E-07	1.3E-06	8.9E-12	3.4E-09	4.4E-11	4.5E-11
2R2	23	821	3.1E+03	1.2E-03	6.1E-01	200440	20000	1.4E-04	2.1E-07	3.9E-09	6.7E-07	1.1E-06	7.3E-12	2.8E-09	3.7E-11	3.7E-11
2R2	24	824	1.8E+03	6.6E-04	6.1E-01	200440	20000	8.0E-05	1.2E-07	2.2E-09	3.8E-07	6.1E-07	4.2E-12	1.6E-09	2.1E-11	2.1E-11
2R2	25	820	4.4E+03	1.6E-03	5.9E-01	220440	24000	2.1E-04	2.9E-07	6.8E-09	9.3E-07	2.0E-06	7.2E-12	3.2E-09	5.8E-11	5.9E-11
2R2	26	821	3.6E+03	1.3E-03	5.9E-01	220440	24000	1.8E-04	2.4E-07	5.6E-09	7.7E-07	1.7E-06	5.9E-12	2.6E-09	4.8E-11	4.9E-11
2R2	27	824	2.1E+03	7.6E-04	5.9E-01	220440	24000	1.0E-04	1.4E-07	3.2E-09	4.4E-07	9.7E-07	3.4E-12	1.5E-09	2.7E-11	2.8E-11
2R2	28	820	5.0E+03	1.8E-03	5.7E-01	244440	20000	1.8E-04	1.7E-07	6.0E-09	6.0E-07	2.0E-06	3.4E-12	1.7E-09	4.5E-11	4.6E-11
2R2	29	821	4.1E+03	1.5E-03	5.7E-01	244440	20000	1.5E-04	1.4E-07	4.9E-09	5.0E-07	1.7E-06	2.8E-12	1.4E-09	3.7E-11	3.8E-11
2R2	30	824	2.4E+03	8.6E-04	5.7E-01	244440	20000	8.6E-05	7.9E-08	2.8E-09	2.8E-07	9.4E-07	1.6E-12	7.9E-10	2.1E-11	2.2E-11
2R2	31	820	5.5E+03	2.0E-03	5.5E-01	264440	20000	1.9E-04	1.1E-07	6.6E-09	4.8E-07	2.5E-06	2.1E-12	1.1E-09	4.1E-11	4.2E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R2	32	821	4.6E+03	1.7E-03	5.5E-01	264440	20000	1.5E-04	9.4E-08	5.5E-09	3.9E-07	2.1E-06	1.7E-12	8.9E-10	3.4E-11	3.5E-11
2R2	33	824	2.6E+03	9.5E-04	5.5E-01	264440	20000	8.8E-05	5.4E-08	3.1E-09	2.3E-07	1.2E-06	9.8E-13	5.1E-10	1.9E-11	2.0E-11
2R2	34	820	6.1E+03	2.2E-03	5.4E-01	284440	24000	2.3E-04	8.9E-08	1.2E-08	4.5E-07	7.3E-06	1.5E-12	1.6E-05	4.6E-11	4.8E-11
2R2	35	821	5.1E+03	1.8E-03	5.4E-01	284440	24000	1.9E-04	7.4E-08	1.0E-08	3.7E-07	6.1E-06	1.3E-12	1.3E-05	3.8E-11	4.0E-11
2R2	36	824	2.9E+03	1.1E-03	5.4E-01	284440	24000	1.1E-04	4.2E-08	5.7E-09	2.1E-07	3.5E-06	7.2E-13	7.7E-06	2.2E-11	2.3E-11
2R2	37	820	6.8E+03	2.5E-03	5.3E-01	308440	20000	1.9E-04	5.0E-08	1.1E-08	1.8E-07	5.1E-06	1.1E-12	2.0E-05	2.3E-11	2.4E-11
2R2	38	821	5.6E+03	2.0E-03	5.3E-01	308440	20000	1.6E-04	4.1E-08	9.4E-09	1.5E-07	4.2E-06	9.0E-13	1.7E-05	1.9E-11	2.0E-11
2R2	39	824	3.2E+03	1.2E-03	5.3E-01	308440	20000	9.1E-05	2.4E-08	5.3E-09	8.5E-08	2.4E-06	5.1E-13	9.4E-06	1.1E-11	1.1E-11
2R2	40	820	7.5E+03	2.7E-03	5.3E-01	328440	24000	2.3E-04	8.1E-08	2.0E-08	1.7E-07	2.1E-06	2.4E-12	7.8E-06	2.9E-11	3.0E-11
2R2	41	821	6.2E+03	2.2E-03	5.3E-01	328440	24000	1.9E-04	6.7E-08	1.6E-08	1.4E-07	1.8E-06	2.0E-12	6.4E-06	2.4E-11	2.5E-11
2R2	42	824	3.5E+03	1.3E-03	5.3E-01	328440	24000	1.1E-04	3.8E-08	9.3E-09	7.9E-08	1.0E-06	1.1E-12	3.7E-06	1.4E-11	1.4E-11
2R2	43	820	8.2E+03	2.9E-03	5.2E-01	352440	20000	2.0E-04	8.1E-08	2.4E-08	1.4E-07	9.4E-07	2.6E-12	3.4E-06	3.2E-11	3.3E-11
2R2	44	821	6.7E+03	2.4E-03	5.2E-01	352440	20000	1.6E-04	6.7E-08	2.0E-08	1.2E-07	7.7E-07	2.2E-12	2.8E-06	2.6E-11	2.7E-11
2R2	45	824	3.8E+03	1.4E-03	5.2E-01	352440	20000	9.3E-05	3.8E-08	1.1E-08	6.8E-08	4.4E-07	1.3E-12	1.6E-06	1.5E-11	1.5E-11
2R2	46	820	8.8E+03	3.1E-03	5.2E-01	372440	20000	2.0E-04	7.9E-08	2.9E-08	1.5E-07	5.9E-07	2.6E-12	2.1E-06	3.7E-11	3.7E-11
2R2	47	821	7.2E+03	2.6E-03	5.2E-01	372440	20000	1.6E-04	6.5E-08	2.4E-08	1.2E-07	4.9E-07	2.1E-12	1.8E-06	3.0E-11	3.1E-11
2R2	48	824	4.1E+03	1.5E-03	5.2E-01	372440	20000	9.3E-05	3.7E-08	1.4E-08	7.0E-08	2.8E-07	1.2E-12	1.0E-06	1.7E-11	1.8E-11
2R2	49	820	9.4E+03	3.4E-03	5.1E-01	392440	24000	2.4E-04	8.0E-08	3.8E-08	1.8E-07	4.4E-07	2.9E-12	1.6E-06	4.7E-11	4.8E-11
2R2	50	821	7.8E+03	2.8E-03	5.1E-01	392440	24000	2.0E-04	6.6E-08	3.2E-08	1.5E-07	3.7E-07	2.4E-12	1.3E-06	3.9E-11	3.9E-11
2R2	51	824	4.4E+03	1.6E-03	5.1E-01	392440	24000	1.1E-04	3.8E-08	1.8E-08	8.4E-08	2.1E-07	1.4E-12	7.6E-07	2.2E-11	2.2E-11
2R2	52	820	1.0E+04	3.6E-03	5.1E-01	416440	20000	2.0E-04	5.3E-08	3.3E-08	1.4E-07	2.3E-07	2.2E-12	8.5E-07	3.9E-11	3.9E-11
2R2	53	821	8.3E+03	3.0E-03	5.1E-01	416440	20000	1.6E-04	4.4E-08	2.7E-08	1.2E-07	1.9E-07	1.8E-12	7.0E-07	3.2E-11	3.3E-11
2R2	54	824	4.7E+03	1.7E-03	5.1E-01	416440	20000	9.4E-05	2.5E-08	1.5E-08	6.8E-08	1.1E-07	1.0E-12	4.0E-07	1.8E-11	1.9E-11
2R2	55	820	1.0E+04	3.6E-03	5.0E-01	436440	24000	2.3E-04	5.2E-08	4.0E-08	1.7E-07	1.9E-07	2.3E-12	6.8E-07	4.6E-11	4.7E-11
2R2	56	821	8.3E+03	3.0E-03	5.0E-01	436440	24000	1.9E-04	4.3E-08	3.3E-08	1.4E-07	1.6E-07	1.9E-12	5.6E-07	3.8E-11	3.9E-11
2R2	57	824	4.8E+03	1.7E-03	5.0E-01	436440	24000	1.1E-04	2.5E-08	1.9E-08	8.2E-08	8.9E-08	1.1E-12	3.2E-07	2.2E-11	2.2E-11
2R2	58	27	1.1E+07	2.8E+00	9.8E-01	452440	4000.2	9.4E-04	1.7E-07	1.4E-07	6.3E-07	5.7E-07	7.8E-12	2.1E-06	1.7E-10	1.7E-10
2R2	59	844	2.7E+07	1.0E+01	5.6E-01	452440	4000.2	4.1E-02	9.4E-06	7.7E-06	3.2E-05	3.1E-05	4.2E-10	1.1E-04	8.9E-09	9.1E-09
2R2	60	27	8.4E+06	2.1E+00	9.6E-01	456440	3999.8	3.2E-03	4.8E-07	3.9E-07	2.0E-06	1.5E-06	2.1E-11	5.6E-06	4.6E-10	4.7E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R2	61	844	1.4E+07	4.9E+00	5.3E-01	456440	3999.8	4.9E-02	1.1E-05	9.4E-06	3.9E-05	3.6E-05	5.0E-10	1.3E-04	1.1E-08	1.1E-08
2R2	62	27	8.2E+06	2.1E+00	9.7E-01	460440	4000.1	4.8E-03	5.2E-07	4.3E-07	2.5E-06	1.6E-06	2.3E-11	5.8E-06	5.0E-10	5.1E-10
2R2	63	820	7.3E+03	2.6E-03	4.9E-01	460440	20000	1.3E-04	3.9E-08	2.7E-08	1.1E-07	8.8E-08	1.4E-12	3.2E-07	3.3E-11	3.3E-11
2R2	64	821	6.0E+03	2.1E-03	4.9E-01	460440	20000	1.1E-04	3.2E-08	2.2E-08	9.3E-08	7.2E-08	1.2E-12	2.7E-07	2.7E-11	2.8E-11
2R2	65	844	1.3E+07	4.6E+00	5.3E-01	460440	4000.1	4.5E-02	1.1E-05	8.8E-06	3.6E-05	3.1E-05	4.7E-10	1.1E-04	1.0E-08	1.1E-08
2R2	66	27	7.7E+06	1.9E+00	9.8E-01	464440	4000.1	5.3E-03	4.0E-07	3.2E-07	2.2E-06	1.1E-06	1.7E-11	4.1E-06	3.8E-10	3.9E-10
2R2	67	844	1.2E+07	4.2E+00	5.4E-01	464440	4000.1	4.1E-02	1.1E-05	8.3E-06	3.4E-05	2.7E-05	4.4E-10	1.0E-04	9.8E-09	1.0E-08
2R2	68	27	7.4E+06	1.8E+00	9.7E-01	468440	3999.7	6.5E-03	2.5E-07	1.9E-07	1.5E-06	6.4E-07	1.0E-11	2.3E-06	2.3E-10	2.3E-10
2R2	69	844	1.1E+07	3.9E+00	5.4E-01	468440	3999.7	3.7E-02	1.1E-05	7.6E-06	3.1E-05	2.4E-05	4.0E-10	8.7E-05	9.2E-09	9.4E-09
2R2	70	27	7.4E+06	1.9E+00	9.5E-01	472440	4000.1	8.6E-03	2.4E-07	1.6E-07	1.3E-06	4.8E-07	8.3E-12	1.8E-06	1.9E-10	2.0E-10
2R2	71	844	9.6E+06	3.4E+00	5.4E-01	472440	4000.1	3.2E-02	1.1E-05	6.8E-06	2.8E-05	2.0E-05	3.6E-10	7.3E-05	8.4E-09	8.6E-09
2R2	72	27	7.2E+06	1.9E+00	9.4E-01	476440	4000.1	9.4E-03	4.0E-07	2.3E-07	1.7E-06	6.4E-07	1.2E-11	2.4E-06	2.8E-10	2.9E-10
2R2	73	844	8.7E+06	3.1E+00	5.4E-01	476440	4000.1	2.8E-02	1.3E-05	6.4E-06	2.6E-05	1.7E-05	3.6E-10	6.3E-05	8.2E-09	8.3E-09
2R2	74	27	7.0E+06	1.8E+00	9.3E-01	480440	3999.9	1.0E-02	4.8E-07	2.3E-07	1.7E-06	5.8E-07	1.3E-11	2.2E-06	2.9E-10	3.0E-10
2R2	75	820	5.0E+03	1.8E-03	4.9E-01	480440	20000	8.3E-05	9.6E-08	2.2E-08	8.3E-08	4.5E-08	1.4E-12	1.8E-07	3.0E-11	3.1E-11
2R2	76	844	7.9E+06	2.8E+00	5.4E-01	480440	3999.9	2.5E-02	1.5E-05	6.1E-06	2.4E-05	1.4E-05	3.6E-10	5.5E-05	7.9E-09	8.1E-09
2R2	77	27	6.9E+06	1.8E+00	9.3E-01	484440	4000.2	1.1E-02	6.1E-07	2.3E-07	1.6E-06	5.3E-07	1.3E-11	2.0E-06	3.0E-10	3.0E-10
2R2	78	844	7.1E+06	2.6E+00	5.4E-01	484440	4000.2	2.2E-02	1.9E-05	5.7E-06	2.2E-05	1.2E-05	3.5E-10	4.8E-05	7.7E-09	7.8E-09
2R2	79	27	6.8E+06	1.8E+00	9.2E-01	488440	3999.9	1.1E-02	8.1E-07	2.3E-07	1.6E-06	4.8E-07	1.4E-11	1.9E-06	3.1E-10	3.2E-10
2R2	80	844	6.4E+06	2.3E+00	5.4E-01	488440	3999.9	2.0E-02	2.4E-05	5.3E-06	2.0E-05	1.0E-05	3.5E-10	4.2E-05	7.4E-09	7.6E-09
2R2	81	27	6.7E+06	1.7E+00	9.2E-01	492440	3999.9	1.1E-02	1.1E-06	2.2E-07	1.5E-06	4.4E-07	1.5E-11	1.8E-06	3.2E-10	3.2E-10
2R2	82	844	5.8E+06	2.1E+00	5.4E-01	492440	3999.9	1.7E-02	3.1E-05	4.8E-06	1.8E-05	8.5E-06	3.2E-10	3.9E-05	6.9E-09	7.1E-09
2R2	83	27	6.6E+06	1.7E+00	9.2E-01	496440	4000	1.2E-02	1.6E-06	2.2E-07	1.5E-06	3.9E-07	1.5E-11	1.8E-06	3.3E-10	3.4E-10
2R2	84	844	5.1E+06	1.9E+00	5.4E-01	496440	4000	1.5E-02	3.9E-05	4.4E-06	1.6E-05	7.1E-06	3.2E-10	3.6E-05	6.7E-09	6.9E-09
2R2	85	27	6.5E+06	1.7E+00	9.1E-01	500440	4000.1	1.2E-02	2.2E-06	2.2E-07	1.5E-06	3.6E-07	1.6E-11	1.9E-06	3.4E-10	3.5E-10
2R2	86	844	4.6E+06	1.6E+00	5.4E-01	500440	4000.1	1.3E-02	5.1E-05	3.9E-06	1.5E-05	5.8E-06	2.8E-10	3.5E-05	6.2E-09	6.4E-09
2R2	87	27	6.5E+06	1.7E+00	9.1E-01	504440	4000	1.2E-02	3.1E-06	2.2E-07	1.5E-06	3.3E-07	1.7E-11	2.0E-06	3.6E-10	3.8E-10
2R2	88	844	4.0E+06	1.5E+00	5.4E-01	504440	4000	1.1E-02	6.2E-05	3.6E-06	1.3E-05	4.7E-06	2.9E-10	3.4E-05	6.0E-09	6.3E-09
2R2	89	27	6.4E+06	1.7E+00	9.1E-01	508440	4000	1.2E-02	4.1E-06	2.2E-07	1.4E-06	2.9E-07	1.8E-11	2.2E-06	3.7E-10	3.9E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R2	90	844	3.5E+06	1.3E+00	5.4E-01	508440	4000	9.2E-03	7.6E-05	3.2E-06	1.2E-05	3.8E-06	2.7E-10	3.4E-05	5.6E-09	5.9E-09
2R2	91	27	6.4E+06	1.7E+00	9.0E-01	512440	3999.9	1.3E-02	5.7E-06	2.2E-07	1.4E-06	2.6E-07	1.8E-11	2.5E-06	3.9E-10	4.2E-10
2R2	92	844	3.1E+06	1.1E+00	5.4E-01	512440	3999.9	7.6E-03	8.9E-05	2.8E-06	1.1E-05	3.0E-06	2.5E-10	3.5E-05	5.2E-09	5.7E-09
2R2	93	27	6.3E+06	1.7E+00	9.0E-01	516440	4000.2	1.3E-02	7.6E-06	2.1E-07	1.4E-06	2.3E-07	1.8E-11	2.9E-06	4.0E-10	4.4E-10
2R2	94	844	2.6E+06	9.5E-01	5.4E-01	516440	4000.2	6.3E-03	1.0E-04	2.3E-06	9.9E-06	2.3E-06	2.0E-10	3.7E-05	4.6E-09	5.2E-09
2R2	95	27	6.3E+06	1.7E+00	9.0E-01	520440	3999.8	1.3E-02	9.8E-06	2.0E-07	1.4E-06	2.0E-07	1.8E-11	3.4E-06	4.1E-10	4.8E-10
2R2	96	844	2.2E+06	8.0E-01	5.4E-01	520440	3999.8	5.1E-03	1.1E-04	1.9E-06	8.7E-06	1.7E-06	1.8E-10	3.8E-05	4.2E-09	5.0E-09
2R2	97	27	6.3E+06	1.7E+00	9.0E-01	524440	4000	1.3E-02	1.3E-05	2.0E-07	1.4E-06	1.7E-07	1.9E-11	4.1E-06	4.4E-10	5.3E-10
2R2	98	820	2.5E+03	8.6E-04	4.8E-01	524440	20000	2.8E-05	1.3E-06	1.2E-08	6.3E-08	8.7E-09	1.3E-12	3.9E-07	3.3E-11	4.5E-11
2R2	99	821	2.0E+03	7.1E-04	4.8E-01	524440	20000	2.3E-05	1.1E-06	1.0E-08	5.2E-08	7.2E-09	1.1E-12	3.2E-07	2.7E-11	3.7E-11
2R2	100	844	1.8E+06	6.6E-01	5.4E-01	524440	4000	4.0E-03	1.2E-04	1.6E-06	7.5E-06	1.3E-06	1.5E-10	3.8E-05	3.7E-09	4.7E-09
2R2	101	27	6.2E+06	1.7E+00	8.9E-01	528440	4000.2	1.3E-02	1.6E-05	2.0E-07	1.4E-06	1.5E-07	2.0E-11	5.0E-06	4.8E-10	6.1E-10
2R2	102	844	1.5E+06	5.3E-01	5.4E-01	528440	4000.2	3.1E-03	1.2E-04	1.3E-06	6.4E-06	9.1E-07	1.3E-10	3.7E-05	3.3E-09	4.3E-09
2R2	103	27	6.2E+06	1.7E+00	8.9E-01	532440	3999.8	1.3E-02	2.0E-05	2.0E-07	1.5E-06	1.4E-07	2.1E-11	6.0E-06	5.2E-10	7.0E-10
2R2	104	844	1.1E+06	4.0E-01	5.4E-01	532440	3999.8	2.2E-03	1.1E-04	9.9E-07	5.2E-06	6.6E-07	1.1E-10	3.4E-05	2.7E-09	3.8E-09
2R2	105	27	6.2E+06	1.6E+00	8.9E-01	536440	4000.2	1.3E-02	2.4E-05	2.0E-07	1.5E-06	1.3E-07	2.1E-11	7.1E-06	5.6E-10	8.0E-10
2R2	106	844	7.9E+05	2.9E-01	5.4E-01	536440	4000.2	1.5E-03	9.6E-05	7.0E-07	3.9E-06	4.7E-07	8.0E-11	2.8E-05	2.1E-09	3.1E-09
2R2	107	27	6.2E+06	1.6E+00	8.8E-01	540440	3999.9	1.3E-02	2.9E-05	2.1E-07	1.6E-06	1.3E-07	2.5E-11	8.3E-06	6.2E-10	8.8E-10
2R2	108	844	4.7E+05	1.7E-01	5.5E-01	540440	3999.9	8.6E-04	6.7E-05	4.5E-07	2.5E-06	2.7E-07	5.8E-11	1.9E-05	1.4E-09	1.9E-09
2R2	109	27	6.1E+06	1.6E+00	8.8E-01	544440	3999.9	1.2E-02	2.9E-05	2.0E-07	1.6E-06	1.3E-07	2.6E-11	8.5E-06	6.5E-10	8.4E-10
2R2	110	820	1.8E+03	6.4E-04	4.8E-01	544440	24000	2.0E-05	1.5E-06	1.1E-08	1.0E-07	1.0E-08	1.7E-12	4.1E-07	5.4E-11	4.9E-11
2R2	111	821	1.5E+03	5.3E-04	4.8E-01	544440	24000	1.6E-05	1.2E-06	9.4E-09	8.2E-08	8.2E-09	1.4E-12	3.4E-07	4.5E-11	4.0E-11
2R2	112	844	2.0E+05	7.1E-02	5.5E-01	544440	3999.9	3.4E-04	2.8E-05	1.9E-07	1.1E-06	1.3E-07	2.5E-11	8.0E-06	6.4E-10	7.9E-10
2R2	113	27	6.2E+06	1.7E+00	8.8E-01	548440	4000.2	1.2E-02	2.7E-05	1.9E-07	1.7E-06	1.7E-07	2.6E-11	7.7E-06	6.9E-10	8.1E-10
2R2	114	844	9.6E+03	3.5E-03	5.5E-01	548440	4000.2	1.6E-05	1.2E-06	8.9E-09	6.0E-08	8.4E-09	1.2E-12	3.5E-07	3.3E-11	3.8E-11
2R2	115	27	6.6E+06	1.7E+00	8.8E-01	552440	4000	1.3E-02	2.7E-05	2.0E-07	2.0E-06	2.1E-07	2.8E-11	7.6E-06	8.3E-10	8.6E-10
2R2	116	27	6.9E+06	1.8E+00	8.8E-01	556440	3999.8	1.3E-02	2.6E-05	2.1E-07	2.3E-06	2.0E-07	3.0E-11	7.3E-06	1.0E-09	9.0E-10
2R2	117	27	7.2E+06	1.9E+00	8.8E-01	560440	4000	1.3E-02	2.6E-05	2.2E-07	2.7E-06	2.0E-07	3.4E-11	7.2E-06	1.2E-09	9.6E-10
2R2	118	27	7.5E+06	2.0E+00	8.8E-01	564440	4000	1.3E-02	2.5E-05	2.3E-07	3.2E-06	1.8E-07	3.9E-11	6.7E-06	1.5E-09	9.9E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
2R2	119	27	7.8E+06	2.1E+00	8.8E-01	568440	4000	1.3E-02	2.3E-05	2.4E-07	3.7E-06	1.6E-07	4.8E-11	6.0E-06	1.8E-09	1.0E-09
2R2	120	820	1.4E+03	5.0E-04	4.7E-01	568440	20000	9.2E-06	5.4E-07	6.8E-09	1.6E-07	3.7E-09	2.6E-12	1.4E-07	9.5E-11	3.0E-11
2R2	121	821	1.2E+03	4.1E-04	4.7E-01	568440	20000	7.6E-06	4.4E-07	5.6E-09	1.3E-07	3.0E-09	2.2E-12	1.1E-07	7.8E-11	2.5E-11
2R2	122	27	8.0E+06	2.1E+00	8.9E-01	572440	3999.9	1.3E-02	2.1E-05	2.4E-07	4.3E-06	1.5E-07	5.8E-11	5.5E-06	2.3E-09	1.0E-09
2R2	123	27	8.3E+06	2.2E+00	8.9E-01	576440	4000.2	1.3E-02	1.8E-05	2.2E-07	5.0E-06	1.3E-07	7.1E-11	4.7E-06	2.7E-09	1.0E-09
2R2	124	27	8.5E+06	2.2E+00	8.9E-01	580440	3999.8	1.2E-02	1.7E-05	2.2E-07	5.9E-06	1.1E-07	9.5E-11	4.3E-06	3.5E-09	1.0E-09
2R2	125	27	8.7E+06	2.3E+00	8.9E-01	584440	4000.1	1.2E-02	1.5E-05	2.2E-07	7.0E-06	1.0E-07	1.3E-10	3.8E-06	4.3E-09	1.0E-09
2R2	126	27	8.9E+06	2.3E+00	9.0E-01	588440	4000	1.1E-02	1.4E-05	2.4E-07	8.2E-06	9.6E-08	1.8E-10	3.4E-06	5.4E-09	1.1E-09
2R2	127	820	1.2E+03	4.1E-04	4.7E-01	588440	16000	4.6E-06	2.1E-07	4.8E-09	2.2E-07	1.7E-09	6.7E-12	5.0E-08	1.1E-10	2.2E-11
2R2	128	821	9.7E+02	3.4E-04	4.7E-01	588440	16000	3.8E-06	1.7E-07	3.9E-09	1.8E-07	1.4E-09	5.5E-12	4.2E-08	9.3E-11	1.8E-11
2R2	129	27	9.1E+06	2.4E+00	9.0E-01	592440	4000.2	1.1E-02	1.2E-05	2.4E-07	9.7E-06	9.1E-08	2.5E-10	3.0E-06	6.1E-09	1.1E-09
2R2	130	27	9.2E+06	2.4E+00	9.0E-01	596440	4000	1.0E-02	1.1E-05	2.4E-07	1.1E-05	8.9E-08	3.4E-10	2.7E-06	5.9E-09	1.1E-09
2R2	131	27	9.4E+06	2.4E+00	9.1E-01	600440	3999.8	1.0E-02	9.9E-06	2.6E-07	1.3E-05	8.7E-08	4.6E-10	2.3E-06	5.5E-09	1.2E-09
3A2	1	476	7.7E+06	2.3E+00	2.8E-01	37200	2500	5.1E-02	1.2E-02	1.1E-03	1.1E-02	1.1E-02	2.3E-05	2.1E-03	6.7E-10	6.7E-10
3A2	2	479	9.7E+06	2.8E+00	2.5E-01	37200	3600	3.2E-01	3.0E-02	1.5E-03	3.1E-02	3.1E-02	2.3E-04	6.4E-03	5.0E-09	5.0E-09
3A2	3	820	3.1E+03	8.2E-04	7.4E-01	37200	21600	9.6E-06	1.4E-06	7.1E-08	9.9E-06	2.2E-06	1.2E-08	1.1E-07	3.7E-09	9.0E-11
3A2	4	821	2.6E+03	6.8E-04	7.4E-01	37200	21600	7.9E-06	1.1E-06	5.8E-08	8.2E-06	1.8E-06	9.7E-09	9.4E-08	3.1E-09	7.4E-11
3A2	5	824	1.5E+03	3.9E-04	7.4E-01	37200	21600	4.5E-06	6.4E-07	3.3E-08	4.7E-06	1.0E-06	5.5E-09	5.3E-08	1.8E-09	4.2E-11
3A2	6	479	6.6E+06	1.7E+00	1.8E-01	40800	3600	4.3E-01	2.4E-02	1.8E-04	3.6E-02	2.9E-02	3.6E-04	5.1E-03	1.2E-08	1.2E-08
3A2	7	479	4.8E+06	1.2E+00	2.1E-01	44400	3600.1	7.4E-02	1.0E-02	9.0E-05	4.3E-02	9.8E-03	7.2E-05	1.5E-03	5.3E-09	5.3E-09
3A2	8	479	2.7E+05	6.7E-02	2.0E-01	48000	3600	2.9E-03	2.8E-03	1.3E-04	3.5E-02	3.1E-02	7.0E-07	4.6E-05	1.8E-10	1.8E-10
3A2	9	479	2.5E+05	6.0E-02	2.0E-01	51600	3600	1.7E-04	1.5E-03	4.9E-04	2.0E-02	4.1E-02	4.5E-09	5.5E-06	1.2E-12	1.2E-12
3A2	10	479	2.8E+05	6.6E-02	2.0E-01	55200	3599.9	1.5E-05	6.0E-04	3.2E-04	5.9E-03	5.8E-03	5.8E-11	1.5E-05	1.2E-14	1.1E-14
3A2	11	479	3.0E+05	7.0E-02	1.9E-01	58800	3600	1.3E-06	3.1E-04	1.3E-04	1.1E-03	2.9E-03	0.0E+00	2.0E-05	0.0E+00	0.0E+00
3A2	12	820	4.2E+03	1.1E-03	6.4E-01	58800	21600	2.0E-05	3.9E-06	6.2E-08	1.1E-05	2.3E-06	7.2E-09	7.3E-08	2.3E-09	9.9E-11
3A2	13	821	3.5E+03	9.4E-04	6.4E-01	58800	21600	1.7E-05	3.2E-06	5.1E-08	9.1E-06	1.9E-06	5.9E-09	6.1E-08	1.9E-09	8.2E-11
3A2	14	824	2.0E+03	5.4E-04	6.4E-01	58800	21600	9.6E-06	1.8E-06	2.9E-08	5.2E-06	1.1E-06	3.4E-09	3.5E-08	1.1E-09	4.7E-11
3A2	15	479	3.0E+05	7.0E-02	1.9E-01	62400	3600.1	1.8E-07	3.6E-04	5.1E-05	8.9E-04	2.7E-03	0.0E+00	2.2E-05	0.0E+00	0.0E+00
3A2	16	479	3.1E+05	7.1E-02	1.9E-01	66000	3600	1.2E-07	4.2E-04	2.9E-05	8.0E-04	3.2E-03	0.0E+00	2.3E-05	0.0E+00	0.0E+00

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	17	479	3.2E+05	7.3E-02	1.9E-01	69600	3600	1.8E-07	4.9E-04	2.0E-05	9.4E-04	3.2E-03	0.0E+00	2.3E-05	0.0E+00	0.0E+00
3A2	18	479	3.3E+05	7.5E-02	1.9E-01	73200	3600	6.0E-08	3.7E-04	2.2E-05	1.1E-03	3.3E-03	0.0E+00	2.2E-05	0.0E+00	0.0E+00
3A2	19	479	3.4E+05	7.8E-02	1.9E-01	76800	3600.1	1.2E-07	2.2E-04	2.4E-05	1.2E-03	2.4E-03	0.0E+00	2.1E-05	0.0E+00	0.0E+00
3A2	20	479	3.5E+05	8.1E-02	1.9E-01	80400	3599.8	0.0E+00	2.2E-04	2.7E-05	1.3E-03	2.0E-03	0.0E+00	1.9E-05	0.0E+00	0.0E+00
3A2	21	820	4.8E+03	1.3E-03	5.9E-01	80400	22000	2.2E-05	8.6E-07	9.0E-08	3.2E-06	8.0E-07	8.9E-10	4.4E-08	3.6E-10	7.8E-11
3A2	22	821	4.0E+03	1.1E-03	5.9E-01	80400	22000	1.8E-05	7.1E-07	7.4E-08	2.6E-06	6.6E-07	7.4E-10	3.6E-08	3.0E-10	6.5E-11
3A2	23	824	2.3E+03	6.2E-04	5.9E-01	80400	22000	1.0E-05	4.0E-07	4.2E-08	1.5E-06	3.8E-07	4.2E-10	2.1E-08	1.7E-10	3.7E-11
3A2	24	479	3.6E+05	8.4E-02	1.9E-01	84000	3400.1	6.6E-06	2.3E-04	2.6E-05	1.2E-03	1.8E-03	1.7E-10	2.6E-05	9.2E-11	3.0E-11
3A2	25	479	4.2E+05	9.0E-02	2.1E-01	87400	3999.9	1.8E-04	4.4E-04	1.7E-05	1.3E-03	1.7E-03	3.3E-09	8.9E-05	1.6E-09	5.5E-10
3A2	26	479	4.5E+05	9.5E-02	2.2E-01	91400	3000	1.9E-04	3.4E-04	1.3E-05	9.5E-04	6.8E-04	2.4E-09	7.1E-05	1.3E-09	4.8E-10
3A2	27	479	4.6E+05	9.7E-02	2.2E-01	94400	4000	2.7E-04	4.8E-04	1.8E-05	1.3E-03	2.3E-04	2.9E-09	1.0E-04	1.6E-09	6.4E-10
3A2	28	479	4.8E+05	1.0E-01	2.2E-01	98400	4000.2	2.8E-04	4.9E-04	1.8E-05	1.3E-03	2.3E-04	2.4E-09	1.0E-04	1.4E-09	6.4E-10
3A2	29	479	4.9E+05	1.0E-01	2.3E-01	102400	2999.9	2.1E-04	3.6E-04	1.4E-05	1.0E-03	1.8E-04	1.6E-09	7.6E-05	1.0E-09	4.8E-10
3A2	30	820	5.4E+03	1.5E-03	5.6E-01	102400	21000	2.2E-05	3.6E-07	1.8E-07	1.6E-06	7.4E-07	3.2E-10	1.9E-08	1.8E-10	8.1E-11
3A2	31	821	4.4E+03	1.2E-03	5.6E-01	102400	21000	1.8E-05	3.0E-07	1.5E-07	1.3E-06	6.1E-07	2.6E-10	1.6E-08	1.5E-10	6.7E-11
3A2	32	824	2.5E+03	7.0E-04	5.6E-01	102400	21000	1.0E-05	1.7E-07	8.4E-08	7.6E-07	3.5E-07	1.5E-10	9.1E-09	8.7E-11	3.8E-11
3A2	33	479	5.0E+05	1.1E-01	2.3E-01	105400	4000	2.8E-04	4.6E-04	1.8E-05	1.4E-03	2.3E-04	1.9E-09	9.5E-05	1.3E-09	6.4E-10
3A2	34	479	5.1E+05	1.1E-01	2.3E-01	109400	2999.9	2.2E-04	3.1E-04	4.3E-05	1.0E-03	1.7E-04	1.3E-09	6.4E-05	8.7E-10	4.7E-10
3A2	35	479	5.2E+05	1.1E-01	2.3E-01	112400	4000.2	2.9E-04	3.8E-04	1.7E-05	1.2E-03	2.2E-04	1.5E-09	7.7E-05	1.1E-09	6.4E-10
3A2	36	479	5.3E+05	1.1E-01	2.3E-01	116400	3999.8	2.9E-04	3.4E-04	4.8E-06	1.2E-03	2.1E-04	1.3E-09	6.6E-05	1.0E-09	6.2E-10
3A2	37	479	5.5E+05	1.2E-01	2.3E-01	120400	3000	2.2E-04	2.2E-04	2.8E-06	8.6E-04	1.5E-04	9.3E-10	4.1E-05	7.6E-10	4.7E-10
3A2	38	479	5.6E+05	1.2E-01	2.3E-01	123400	4000	3.0E-04	2.6E-04	3.5E-06	1.1E-03	2.0E-04	1.0E-09	4.5E-05	9.5E-10	6.1E-10
3A2	39	820	6.0E+03	1.7E-03	5.4E-01	123400	22000	2.4E-05	2.5E-07	2.1E-07	1.1E-06	9.0E-07	1.6E-10	1.1E-08	1.4E-10	8.2E-11
3A2	40	821	4.9E+03	1.4E-03	5.4E-01	123400	22000	2.0E-05	2.1E-07	1.7E-07	9.4E-07	7.4E-07	1.4E-10	9.4E-09	1.1E-10	6.8E-11
3A2	41	824	2.8E+03	7.9E-04	5.4E-01	123400	22000	1.1E-05	1.2E-07	1.0E-07	5.3E-07	4.2E-07	7.7E-11	5.4E-09	6.4E-11	3.9E-11
3A2	42	479	5.7E+05	1.2E-01	2.3E-01	127400	3000.2	2.3E-04	1.7E-04	2.5E-06	8.4E-04	1.7E-04	7.6E-10	2.8E-05	6.8E-10	4.5E-10
3A2	43	479	5.8E+05	1.3E-01	2.3E-01	130400	4000	3.1E-04	2.0E-04	3.1E-06	1.1E-03	2.7E-04	8.1E-10	2.9E-05	8.6E-10	5.8E-10
3A2	44	479	6.0E+05	1.3E-01	2.3E-01	134400	3999.9	3.1E-04	1.8E-04	5.7E-05	1.3E-03	3.0E-04	7.6E-10	2.1E-05	7.4E-10	5.2E-10
3A2	45	479	6.1E+05	1.3E-01	2.3E-01	138400	2999.9	2.3E-04	1.3E-04	3.5E-05	1.0E-03	2.4E-04	3.5E-10	1.2E-05	5.0E-10	3.6E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	46	479	6.2E+05	1.4E-01	2.3E-01	141400	4000	3.0E-04	1.6E-04	6.7E-06	1.4E-03	1.7E-04	7.6E-10	1.2E-05	5.9E-10	4.4E-10
3A2	47	479	6.2E+05	1.4E-01	2.3E-01	145400	3000.2	2.0E-04	9.9E-05	8.3E-07	8.3E-04	1.5E-05	8.7E-10	7.1E-06	4.1E-10	3.1E-10
3A2	48	820	6.6E+03	1.9E-03	5.2E-01	145400	21000	2.3E-05	2.0E-07	1.7E-07	8.1E-07	9.6E-07	8.6E-11	6.9E-09	1.0E-10	7.4E-11
3A2	49	821	5.5E+03	1.6E-03	5.2E-01	145400	21000	1.9E-05	1.6E-07	1.4E-07	6.7E-07	8.0E-07	7.1E-11	5.7E-09	8.3E-11	6.1E-11
3A2	50	824	3.1E+03	8.9E-04	5.2E-01	145400	21000	1.1E-05	9.3E-08	8.2E-08	3.8E-07	4.6E-07	4.0E-11	3.2E-09	4.7E-11	3.5E-11
3A2	51	479	6.4E+05	1.4E-01	2.3E-01	148400	4000	3.1E-04	1.4E-04	9.7E-07	1.3E-03	3.4E-05	5.2E-10	8.6E-06	6.5E-10	5.0E-10
3A2	52	479	6.6E+05	1.5E-01	2.3E-01	152400	4000	3.2E-04	1.2E-04	4.3E-07	1.1E-03	2.7E-05	4.1E-10	6.9E-06	6.5E-10	5.1E-10
3A2	53	479	6.7E+05	1.5E-01	2.3E-01	156400	3000	2.4E-04	8.5E-05	1.1E-06	7.8E-04	1.9E-05	2.9E-10	4.2E-06	4.8E-10	3.9E-10
3A2	54	479	6.8E+05	1.5E-01	2.3E-01	159400	3999.8	3.2E-04	1.1E-04	1.5E-06	1.0E-03	2.5E-05	4.7E-10	4.4E-06	6.2E-10	5.0E-10
3A2	55	479	7.0E+05	1.5E-01	2.3E-01	163400	3000.1	2.4E-04	7.6E-05	6.3E-07	7.1E-04	1.8E-05	2.3E-10	2.7E-06	4.6E-10	3.8E-10
3A2	56	479	7.1E+05	1.6E-01	2.3E-01	166400	3999.9	3.3E-04	9.2E-05	8.1E-07	8.3E-04	2.2E-05	3.5E-10	2.9E-06	6.1E-10	5.1E-10
3A2	57	820	7.3E+03	2.1E-03	5.0E-01	166400	22086	2.4E-05	1.8E-07	1.4E-07	6.7E-07	1.2E-06	5.4E-11	4.6E-09	8.8E-11	7.2E-11
3A2	58	821	6.0E+03	1.7E-03	5.0E-01	166400	22086	2.0E-05	1.5E-07	1.1E-07	5.5E-07	9.6E-07	4.4E-11	3.8E-09	7.3E-11	6.0E-11
3A2	59	824	3.4E+03	9.9E-04	5.0E-01	166400	22086	1.2E-05	8.5E-08	6.5E-08	3.1E-07	5.5E-07	2.5E-11	2.2E-09	4.1E-11	3.4E-11
3A2	60	479	7.2E+05	1.6E-01	2.3E-01	170400	2400	2.0E-04	5.5E-05	4.6E-07	5.0E-04	1.4E-05	1.7E-10	1.5E-06	3.6E-10	3.0E-10
3A2	61	479	7.3E+05	1.6E-01	2.3E-01	172800	4000.3	3.3E-04	8.9E-05	6.8E-07	8.1E-04	2.2E-05	3.5E-10	2.0E-06	5.9E-10	5.0E-10
3A2	62	479	7.5E+05	1.7E-01	2.3E-01	176800	3999.8	3.3E-04	8.8E-05	6.3E-07	8.1E-04	2.2E-05	2.3E-10	1.6E-06	5.7E-10	5.0E-10
3A2	63	479	7.6E+05	1.7E-01	2.3E-01	180800	3999.9	3.3E-04	7.6E-05	7.5E-07	6.5E-04	1.8E-05	2.9E-10	1.3E-06	5.7E-10	5.0E-10
3A2	64	479	7.7E+05	1.7E-01	2.3E-01	184800	3686	3.1E-04	7.7E-05	8.2E-07	6.9E-04	1.9E-05	2.3E-10	9.5E-07	5.1E-10	4.5E-10
3A2	65	479	7.9E+05	1.8E-01	2.3E-01	188490	4314.1	3.6E-04	8.6E-05	9.2E-07	7.5E-04	2.2E-05	2.3E-10	9.0E-07	5.9E-10	5.3E-10
3A2	66	820	7.9E+03	2.3E-03	4.9E-01	188490	20314	2.3E-05	1.4E-07	9.3E-08	4.9E-07	1.3E-06	3.1E-11	2.8E-09	7.0E-11	6.1E-11
3A2	67	821	6.5E+03	1.9E-03	4.9E-01	188490	20314	1.9E-05	1.2E-07	7.7E-08	4.0E-07	1.1E-06	2.6E-11	2.3E-09	5.7E-11	5.1E-11
3A2	68	824	3.7E+03	1.1E-03	4.9E-01	188490	20314	1.1E-05	6.6E-08	4.4E-08	2.3E-07	6.1E-07	1.5E-11	1.3E-09	3.3E-11	2.9E-11
3A2	69	479	8.0E+05	1.8E-01	2.3E-01	192800	3840.3	3.2E-04	7.4E-05	7.7E-07	6.4E-04	1.9E-05	1.7E-10	6.4E-07	5.2E-10	4.7E-10
3A2	70	479	8.2E+05	1.9E-01	2.3E-01	196640	3323.6	2.8E-04	5.1E-05	6.2E-07	4.6E-04	1.4E-05	1.7E-10	4.6E-07	4.5E-10	4.1E-10
3A2	71	479	8.3E+05	1.9E-01	2.3E-01	199960	3672.8	3.1E-04	5.6E-05	6.5E-07	5.5E-04	1.7E-05	1.7E-10	4.2E-07	4.9E-10	4.5E-10
3A2	72	479	8.4E+05	1.9E-01	2.3E-01	203640	4198.9	3.6E-04	6.6E-05	6.4E-07	6.5E-04	2.0E-05	1.2E-10	3.7E-07	5.1E-10	4.8E-10
3A2	73	479	8.5E+05	1.9E-01	2.3E-01	207840	964.3	8.2E-05	1.3E-05	1.6E-07	1.2E-04	4.1E-06	5.8E-11	7.6E-08	1.3E-10	1.2E-10
3A2	74	479	8.6E+05	2.0E-01	2.3E-01	208800	4000.1	3.4E-04	5.3E-05	6.6E-07	4.9E-04	1.8E-05	1.2E-10	2.8E-07	5.3E-10	4.9E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	75	820	8.6E+03	2.5E-03	4.8E-01	208800	23507	2.6E-05	1.3E-07	8.1E-08	4.6E-07	2.3E-06	2.4E-11	2.4E-09	7.2E-11	6.8E-11
3A2	76	821	7.1E+03	2.1E-03	4.8E-01	208800	23507	2.2E-05	1.1E-07	6.7E-08	3.8E-07	1.9E-06	2.0E-11	2.0E-09	6.0E-11	5.6E-11
3A2	77	824	4.0E+03	1.2E-03	4.8E-01	208800	23507	1.2E-05	6.3E-08	3.8E-08	2.2E-07	1.1E-06	1.1E-11	1.1E-09	3.4E-11	3.2E-11
3A2	78	479	8.7E+05	2.0E-01	2.4E-01	212800	4000	3.5E-04	4.9E-05	6.5E-07	4.4E-04	1.7E-05	1.7E-10	2.3E-07	5.3E-10	5.0E-10
3A2	79	479	8.9E+05	2.1E-01	2.4E-01	216800	3999.9	3.5E-04	5.1E-05	6.0E-07	4.7E-04	1.9E-05	1.2E-10	1.8E-07	5.0E-10	4.8E-10
3A2	80	479	9.0E+05	2.1E-01	2.4E-01	220800	3805	3.3E-04	5.6E-05	4.7E-07	5.5E-04	1.9E-05	1.2E-10	1.3E-07	4.2E-10	4.0E-10
3A2	81	479	9.1E+05	2.1E-01	2.4E-01	224610	4195.1	3.6E-04	6.4E-05	4.5E-07	6.3E-04	2.3E-05	1.7E-10	1.2E-07	4.2E-10	4.1E-10
3A2	82	479	9.3E+05	2.2E-01	2.4E-01	228800	3506.5	3.1E-04	4.5E-05	3.6E-07	4.6E-04	2.1E-05	5.8E-11	9.5E-08	3.6E-10	3.5E-10
3A2	83	479	9.4E+05	2.2E-01	2.4E-01	232310	4493.5	4.0E-04	5.3E-05	4.6E-07	5.4E-04	3.3E-05	1.2E-10	1.8E-07	4.9E-10	4.8E-10
3A2	84	820	9.2E+03	2.7E-03	4.7E-01	232310	20898	2.3E-05	8.4E-08	2.5E-07	2.6E-07	5.7E-06	1.1E-11	4.5E-05	5.0E-11	4.9E-11
3A2	85	821	7.6E+03	2.3E-03	4.7E-01	232310	20898	1.9E-05	6.9E-08	2.1E-07	2.1E-07	4.7E-06	9.4E-12	3.7E-05	4.1E-11	4.0E-11
3A2	86	824	4.3E+03	1.3E-03	4.7E-01	232310	20898	1.1E-05	4.0E-08	1.2E-07	1.2E-07	2.7E-06	5.4E-12	2.1E-05	2.4E-11	2.3E-11
3A2	87	479	9.6E+05	2.3E-01	2.4E-01	236800	4966.6	4.4E-04	5.7E-05	5.0E-07	5.9E-04	7.0E-05	5.8E-11	2.8E-04	5.3E-10	5.3E-10
3A2	88	479	9.7E+05	2.3E-01	2.4E-01	241770	3033.4	2.7E-04	2.7E-05	2.0E-06	2.5E-04	7.2E-05	5.8E-11	1.0E-03	1.8E-10	1.8E-10
3A2	89	479	9.9E+05	2.3E-01	2.5E-01	244800	4000.2	3.6E-04	3.2E-05	9.5E-06	2.9E-04	4.5E-05	5.8E-11	4.1E-04	3.2E-10	3.2E-10
3A2	90	479	1.0E+06	2.4E-01	2.5E-01	248800	4404	4.0E-04	3.5E-05	1.2E-05	3.3E-04	2.6E-05	5.8E-11	2.6E-04	3.2E-10	3.2E-10
3A2	91	479	1.0E+06	2.4E-01	2.5E-01	253200	3596	3.3E-04	2.8E-05	1.0E-05	2.6E-04	1.5E-05	0.0E+00	1.6E-04	2.6E-10	2.6E-10
3A2	92	820	9.9E+03	3.0E-03	4.6E-01	253200	23596	2.6E-05	8.8E-08	6.8E-07	1.0E-07	2.8E-06	4.0E-12	2.3E-05	3.3E-11	3.3E-11
3A2	93	821	8.2E+03	2.5E-03	4.6E-01	253200	23596	2.1E-05	7.3E-08	5.6E-07	8.6E-08	2.3E-06	3.3E-12	1.9E-05	2.7E-11	2.7E-11
3A2	94	824	4.7E+03	1.4E-03	4.6E-01	253200	23596	1.2E-05	4.2E-08	3.2E-07	4.9E-08	1.3E-06	1.9E-12	1.1E-05	1.6E-11	1.6E-11
3A2	95	479	1.0E+06	2.5E-01	2.5E-01	256800	3999.8	3.6E-04	2.9E-05	9.4E-06	2.7E-04	1.4E-05	5.8E-11	1.4E-04	2.9E-10	2.9E-10
3A2	96	479	1.0E+06	2.5E-01	2.5E-01	260800	4000.3	3.6E-04	2.9E-05	4.0E-06	2.7E-04	1.2E-05	0.0E+00	1.1E-04	2.9E-10	3.0E-10
3A2	97	479	1.1E+06	2.6E-01	2.5E-01	264800	2117.5	1.9E-04	1.5E-05	1.8E-06	1.4E-04	5.4E-06	0.0E+00	5.3E-05	1.6E-10	1.6E-10
3A2	98	479	1.1E+06	2.6E-01	2.5E-01	266920	5882.1	5.4E-04	3.8E-05	4.3E-06	3.5E-04	1.3E-05	5.8E-11	1.3E-04	4.4E-10	4.5E-10
3A2	99	479	1.1E+06	2.7E-01	2.5E-01	272800	4000.1	3.7E-04	2.4E-05	2.7E-06	2.2E-04	7.8E-06	0.0E+00	7.8E-05	3.4E-10	3.5E-10
3A2	100	479	1.1E+06	2.7E-01	2.6E-01	276800	4000.3	3.7E-04	2.3E-05	2.5E-06	2.0E-04	7.0E-06	5.8E-11	7.0E-05	3.6E-10	3.6E-10
3A2	101	820	1.1E+04	3.2E-03	4.6E-01	276800	20000	2.2E-05	9.4E-08	2.9E-07	9.3E-08	1.1E-06	1.9E-11	8.5E-06	4.0E-11	3.5E-11
3A2	102	821	8.8E+03	2.7E-03	4.6E-01	276800	20000	1.8E-05	7.8E-08	2.4E-07	7.7E-08	9.1E-07	1.6E-11	7.0E-06	3.3E-11	2.9E-11
3A2	103	479	1.1E+06	2.8E-01	2.6E-01	280800	3999.8	3.7E-04	2.2E-05	2.4E-06	1.9E-04	6.3E-06	5.8E-11	6.6E-05	3.8E-10	3.9E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	104	479	1.1E+06	2.8E-01	2.6E-01	284800	3999.8	3.7E-04	2.0E-05	2.2E-06	1.7E-04	5.8E-06	0.0E+00	6.0E-05	4.0E-10	4.1E-10
3A2	105	479	1.2E+06	2.9E-01	2.6E-01	288800	4000	3.7E-04	1.9E-05	2.1E-06	1.7E-04	5.3E-06	0.0E+00	5.5E-05	4.1E-10	4.2E-10
3A2	106	479	1.2E+06	2.9E-01	2.6E-01	292800	4000.1	3.6E-04	1.9E-05	1.7E-06	1.7E-04	5.1E-06	2.5E-09	4.6E-05	1.2E-09	4.0E-10
3A2	107	479	1.2E+06	2.9E-01	2.6E-01	296800	4000.2	3.6E-04	1.8E-05	1.7E-06	1.6E-04	4.5E-06	1.2E-09	4.4E-05	7.8E-10	4.3E-10
3A2	108	820	1.1E+04	3.4E-03	4.5E-01	296800	20000	2.2E-05	8.2E-08	1.9E-07	1.5E-07	6.6E-07	8.3E-11	5.0E-06	6.5E-11	4.1E-11
3A2	109	821	9.1E+03	2.8E-03	4.5E-01	296800	20000	1.8E-05	6.8E-08	1.5E-07	1.2E-07	5.5E-07	6.9E-11	4.1E-06	5.4E-11	3.4E-11
3A2	110	824	5.2E+03	1.6E-03	4.5E-01	296800	20000	1.0E-05	3.9E-08	8.8E-08	6.9E-08	3.1E-07	3.9E-11	2.4E-06	3.1E-11	1.9E-11
3A2	111	479	1.2E+06	3.0E-01	2.6E-01	300800	3999.8	3.6E-04	1.7E-05	1.6E-06	1.5E-04	4.1E-06	7.0E-10	4.1E-05	6.4E-10	4.5E-10
3A2	112	479	1.2E+06	3.0E-01	2.6E-01	304800	1649	1.5E-04	6.9E-06	6.5E-07	6.0E-05	1.6E-06	2.9E-10	1.6E-05	2.7E-10	1.9E-10
3A2	113	479	1.2E+06	3.0E-01	2.6E-01	306450	2351.2	2.1E-04	9.6E-06	9.2E-07	8.4E-05	2.2E-06	4.1E-10	2.2E-05	3.8E-10	2.8E-10
3A2	114	479	1.2E+06	3.0E-01	2.6E-01	308800	3999.8	3.6E-04	1.5E-05	1.5E-06	1.3E-04	3.5E-06	5.8E-10	3.6E-05	6.5E-10	4.8E-10
3A2	115	479	1.2E+06	3.0E-01	2.7E-01	312800	4000	3.6E-04	1.4E-05	1.5E-06	1.2E-04	3.2E-06	5.2E-10	3.3E-05	6.5E-10	4.9E-10
3A2	116	479	1.2E+06	3.0E-01	2.7E-01	316800	4000.4	3.6E-04	1.3E-05	1.4E-06	1.1E-04	3.0E-06	6.4E-10	3.1E-05	6.4E-10	5.0E-10
3A2	117	820	1.1E+04	3.4E-03	4.5E-01	316800	24000	2.5E-05	6.7E-08	1.7E-07	1.5E-07	5.1E-07	6.6E-11	3.8E-06	7.3E-11	5.5E-11
3A2	118	821	9.2E+03	2.8E-03	4.5E-01	316800	24000	2.1E-05	5.6E-08	1.4E-07	1.2E-07	4.2E-07	5.4E-11	3.2E-06	6.0E-11	4.5E-11
3A2	119	824	5.3E+03	1.6E-03	4.5E-01	316800	24000	1.2E-05	3.2E-08	7.8E-08	6.9E-08	2.4E-07	3.1E-11	1.8E-06	3.4E-11	2.6E-11
3A2	120	844	3.7E+06	9.4E-01	9.6E-01	316800	4000.4	4.1E-04	9.4E-07	2.3E-06	2.0E-06	7.3E-06	9.4E-10	5.5E-05	9.2E-10	6.5E-10
3A2	121	479	1.2E+06	3.1E-01	2.7E-01	320800	4000	3.5E-04	1.3E-05	1.3E-06	1.1E-04	2.7E-06	4.7E-10	2.8E-05	6.0E-10	4.7E-10
3A2	122	844	4.0E+06	1.0E+00	8.6E-01	320800	4000	6.3E-04	1.3E-06	3.1E-06	2.9E-06	9.9E-06	1.3E-09	7.5E-05	1.3E-09	9.6E-10
3A2	123	479	1.2E+06	3.1E-01	2.7E-01	324800	4000	3.5E-04	1.2E-05	1.3E-06	1.0E-04	2.5E-06	4.1E-10	2.6E-05	6.2E-10	5.0E-10
3A2	124	844	4.2E+06	1.1E+00	8.4E-01	324800	4000	6.3E-04	1.3E-06	3.1E-06	2.9E-06	9.7E-06	1.2E-09	7.3E-05	1.4E-09	1.0E-09
3A2	125	479	1.2E+06	3.1E-01	2.7E-01	328800	4000	3.5E-04	1.1E-05	1.2E-06	9.1E-05	2.3E-06	4.1E-10	2.4E-05	6.2E-10	5.1E-10
3A2	126	844	4.1E+06	1.0E+00	8.4E-01	328800	4000	6.1E-04	1.3E-06	3.2E-06	3.0E-06	9.7E-06	1.3E-09	7.3E-05	1.5E-09	1.1E-09
3A2	127	479	1.2E+06	3.1E-01	2.7E-01	332800	4000	3.5E-04	1.1E-05	1.2E-06	8.8E-05	2.2E-06	4.7E-10	2.3E-05	6.3E-10	5.2E-10
3A2	128	844	4.2E+06	1.1E+00	8.4E-01	332800	4000	6.1E-04	1.3E-06	3.3E-06	3.1E-06	9.7E-06	1.3E-09	7.3E-05	1.6E-09	1.2E-09
3A2	129	479	1.2E+06	3.1E-01	2.7E-01	336800	4000	3.5E-04	1.0E-05	1.1E-06	7.9E-05	2.0E-06	3.5E-10	2.2E-05	6.3E-10	5.3E-10
3A2	130	844	4.4E+06	1.1E+00	8.3E-01	336800	4000	6.1E-04	1.3E-06	3.2E-06	3.1E-06	9.1E-06	1.2E-09	6.8E-05	1.6E-09	1.3E-09
3A2	131	479	1.2E+06	3.1E-01	2.7E-01	340800	4000	3.4E-04	9.6E-06	1.1E-06	7.6E-05	1.8E-06	3.5E-10	2.0E-05	6.3E-10	5.4E-10
3A2	132	820	1.1E+04	3.4E-03	4.4E-01	340800	20000	2.0E-05	5.1E-08	1.1E-07	1.5E-07	3.0E-07	7.4E-11	2.2E-06	6.9E-11	4.8E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	133	821	9.1E+03	2.8E-03	4.4E-01	340800	20000	1.6E-05	4.2E-08	8.8E-08	1.2E-07	2.5E-07	6.1E-11	1.8E-06	5.7E-11	3.9E-11
3A2	134	824	5.2E+03	1.6E-03	4.4E-01	340800	20000	9.4E-06	2.4E-08	5.0E-08	7.0E-08	1.4E-07	3.5E-11	1.0E-06	3.2E-11	2.2E-11
3A2	135	844	4.5E+06	1.2E+00	8.2E-01	340800	4000	6.0E-04	1.2E-06	3.1E-06	3.0E-06	8.5E-06	1.1E-09	6.4E-05	1.6E-09	1.3E-09
3A2	136	479	1.2E+06	3.1E-01	2.7E-01	344800	4000	3.4E-04	9.1E-06	1.1E-06	7.1E-05	1.7E-06	3.5E-10	1.9E-05	6.3E-10	5.4E-10
3A2	137	844	4.6E+06	1.2E+00	8.1E-01	344800	4000	5.9E-04	1.1E-06	3.0E-06	3.0E-06	8.0E-06	1.1E-09	6.0E-05	1.6E-09	1.3E-09
3A2	138	479	1.2E+06	3.1E-01	2.7E-01	348800	4000	3.4E-04	8.7E-06	1.0E-06	6.6E-05	1.7E-06	5.2E-10	1.8E-05	6.9E-10	5.4E-10
3A2	139	844	4.6E+06	1.2E+00	8.0E-01	348800	4000	5.9E-04	1.5E-06	2.8E-06	4.7E-06	8.2E-06	2.5E-09	6.0E-05	2.0E-09	1.3E-09
3A2	140	479	1.2E+06	3.1E-01	2.7E-01	352800	4000	3.4E-04	8.4E-06	9.4E-07	6.3E-05	1.6E-06	8.1E-10	1.7E-05	7.3E-10	5.1E-10
3A2	141	844	4.7E+06	1.2E+00	8.0E-01	352800	4000	5.8E-04	1.5E-06	2.7E-06	4.7E-06	7.7E-06	2.5E-09	5.6E-05	2.0E-09	1.3E-09
3A2	142	479	1.2E+06	3.1E-01	2.7E-01	356800	4000	3.3E-04	8.0E-06	9.4E-07	6.0E-05	1.5E-06	8.1E-10	1.6E-05	7.9E-10	5.3E-10
3A2	143	844	4.7E+06	1.2E+00	7.9E-01	356800	4000	5.8E-04	1.6E-06	2.6E-06	5.6E-06	7.5E-06	3.3E-09	5.3E-05	2.3E-09	1.3E-09
3A2	144	479	1.2E+06	3.1E-01	2.7E-01	360800	4000	3.3E-04	7.8E-06	8.9E-07	5.7E-05	1.5E-06	1.5E-09	1.6E-05	9.6E-10	5.2E-10
3A2	145	820	1.1E+04	3.3E-03	4.4E-01	360800	20000	1.9E-05	7.3E-08	8.3E-08	2.7E-07	2.6E-07	1.8E-10	1.7E-06	1.0E-10	4.5E-11
3A2	146	821	9.0E+03	2.7E-03	4.4E-01	360800	20000	1.6E-05	6.0E-08	6.9E-08	2.3E-07	2.2E-07	1.5E-10	1.4E-06	8.4E-11	3.7E-11
3A2	147	824	5.1E+03	1.6E-03	4.4E-01	360800	20000	9.0E-06	3.4E-08	3.9E-08	1.3E-07	1.2E-07	8.7E-11	8.1E-07	4.8E-11	2.1E-11
3A2	148	844	4.8E+06	1.3E+00	7.9E-01	360800	4000	5.7E-04	2.3E-06	2.4E-06	8.4E-06	8.2E-06	5.8E-09	5.4E-05	3.0E-09	1.2E-09
3A2	149	479	1.2E+06	3.1E-01	2.7E-01	364800	4000	3.3E-04	7.6E-06	8.5E-07	5.5E-05	1.5E-06	1.7E-09	1.6E-05	1.0E-09	5.1E-10
3A2	150	844	4.8E+06	1.3E+00	7.9E-01	364800	4000	5.7E-04	2.1E-06	2.3E-06	8.0E-06	7.6E-06	5.4E-09	5.0E-05	2.9E-09	1.2E-09
3A2	151	479	1.2E+06	3.0E-01	2.7E-01	368800	4000	3.2E-04	7.4E-06	8.2E-07	5.3E-05	1.4E-06	1.6E-09	1.4E-05	9.9E-10	5.1E-10
3A2	152	844	4.8E+06	1.3E+00	7.9E-01	368800	4000	5.6E-04	2.0E-06	2.2E-06	7.5E-06	7.0E-06	5.1E-09	4.6E-05	2.8E-09	1.2E-09
3A2	153	479	1.2E+06	3.0E-01	2.8E-01	372800	4000	3.2E-04	6.8E-06	8.1E-07	4.6E-05	1.3E-06	1.5E-09	1.4E-05	9.8E-10	5.3E-10
3A2	154	844	4.8E+06	1.3E+00	7.9E-01	372800	4000	5.6E-04	1.9E-06	2.2E-06	7.1E-06	6.6E-06	4.7E-09	4.3E-05	2.7E-09	1.3E-09
3A2	155	479	1.2E+06	3.0E-01	2.8E-01	376800	4000	3.2E-04	6.4E-06	8.1E-07	4.1E-05	1.2E-06	1.5E-09	1.3E-05	9.7E-10	5.4E-10
3A2	156	844	4.8E+06	1.3E+00	7.9E-01	376800	4000	5.5E-04	1.8E-06	2.1E-06	6.7E-06	6.1E-06	4.4E-09	4.0E-05	2.6E-09	1.3E-09
3A2	157	479	1.2E+06	3.0E-01	2.8E-01	380800	4000	3.2E-04	6.2E-06	7.9E-07	3.9E-05	1.1E-06	1.3E-09	1.2E-05	9.5E-10	5.5E-10
3A2	158	820	1.0E+04	3.2E-03	4.3E-01	380800	24000	2.2E-05	6.3E-08	8.6E-08	2.4E-07	2.1E-07	1.5E-10	1.4E-06	1.0E-10	5.7E-11
3A2	159	821	8.6E+03	2.6E-03	4.3E-01	380800	24000	1.8E-05	5.2E-08	7.1E-08	2.0E-07	1.7E-07	1.3E-10	1.2E-06	8.5E-11	4.7E-11
3A2	160	824	4.9E+03	1.5E-03	4.3E-01	380800	24000	1.0E-05	3.0E-08	4.0E-08	1.2E-07	1.0E-07	7.2E-11	6.6E-07	4.9E-11	2.7E-11
3A2	161	844	4.8E+06	1.3E+00	7.9E-01	380800	4000	5.5E-04	1.6E-06	2.1E-06	6.4E-06	5.7E-06	4.1E-09	3.7E-05	2.5E-09	1.3E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	162	479	1.2E+06	3.0E-01	2.8E-01	384800	4000	3.2E-04	6.0E-06	7.8E-07	3.7E-05	1.0E-06	1.3E-09	1.1E-05	9.3E-10	5.6E-10
3A2	163	844	4.8E+06	1.3E+00	7.9E-01	384800	4000	5.4E-04	1.6E-06	2.0E-06	6.0E-06	5.3E-06	3.8E-09	3.5E-05	2.4E-09	1.3E-09
3A2	164	479	1.1E+06	3.0E-01	2.8E-01	388800	4000	3.2E-04	5.9E-06	7.8E-07	3.6E-05	9.5E-07	1.2E-09	1.1E-05	9.2E-10	5.7E-10
3A2	165	844	4.8E+06	1.3E+00	7.9E-01	388800	4000	5.4E-04	1.5E-06	2.0E-06	5.7E-06	4.9E-06	3.6E-09	3.2E-05	2.4E-09	1.3E-09
3A2	166	479	1.1E+06	2.9E-01	2.8E-01	392800	4000	3.2E-04	5.6E-06	7.6E-07	3.3E-05	9.4E-07	1.1E-09	1.0E-05	9.0E-10	5.7E-10
3A2	167	844	4.8E+06	1.3E+00	7.9E-01	392800	4000	5.3E-04	1.4E-06	1.9E-06	5.4E-06	4.6E-06	3.3E-09	3.0E-05	2.3E-09	1.3E-09
3A2	168	479	1.1E+06	2.9E-01	2.8E-01	396800	4000	3.2E-04	5.5E-06	7.5E-07	3.2E-05	8.6E-07	1.0E-09	9.5E-06	8.9E-10	5.8E-10
3A2	169	844	4.8E+06	1.3E+00	7.9E-01	396800	4000	5.3E-04	1.3E-06	1.9E-06	5.1E-06	4.3E-06	3.1E-09	2.8E-05	2.3E-09	1.3E-09
3A2	170	479	1.1E+06	2.9E-01	2.8E-01	400800	4000	3.2E-04	5.4E-06	7.3E-07	3.0E-05	7.9E-07	9.3E-10	8.9E-06	8.6E-10	5.8E-10
3A2	171	844	4.8E+06	1.2E+00	7.9E-01	400800	4000	5.2E-04	1.3E-06	1.8E-06	4.9E-06	4.0E-06	2.9E-09	2.6E-05	2.2E-09	1.3E-09
3A2	172	479	1.1E+06	2.9E-01	2.8E-01	404800	4000	3.1E-04	5.3E-06	7.2E-07	3.0E-05	7.6E-07	9.3E-10	8.3E-06	8.5E-10	5.8E-10
3A2	173	820	1.0E+04	3.0E-03	4.3E-01	404800	20000	1.7E-05	4.1E-08	6.2E-08	1.5E-07	1.2E-07	8.7E-11	7.8E-07	7.3E-11	4.8E-11
3A2	174	821	8.3E+03	2.5E-03	4.3E-01	404800	20000	1.4E-05	3.4E-08	5.1E-08	1.3E-07	9.8E-08	7.2E-11	6.5E-07	6.1E-11	4.0E-11
3A2	175	824	4.7E+03	1.4E-03	4.3E-01	404800	20000	8.1E-06	1.9E-08	2.9E-08	7.3E-08	5.6E-08	4.1E-11	3.7E-07	3.5E-11	2.3E-11
3A2	176	844	4.7E+06	1.2E+00	7.9E-01	404800	4000	5.2E-04	1.2E-06	1.8E-06	4.6E-06	3.7E-06	2.7E-09	2.4E-05	2.1E-09	1.3E-09
3A2	177	479	1.1E+06	2.9E-01	2.8E-01	408800	4000	3.1E-04	5.2E-06	6.7E-07	2.9E-05	6.9E-07	8.7E-10	7.8E-06	8.0E-10	5.5E-10
3A2	178	844	4.7E+06	1.2E+00	7.9E-01	408800	4000	5.1E-04	1.1E-06	1.7E-06	4.4E-06	3.4E-06	2.5E-09	2.3E-05	2.1E-09	1.3E-09
3A2	179	479	1.1E+06	2.9E-01	2.8E-01	412800	4000	3.1E-04	5.1E-06	6.8E-07	2.8E-05	6.7E-07	8.1E-10	7.2E-06	8.1E-10	5.8E-10
3A2	180	844	4.7E+06	1.2E+00	7.9E-01	412800	4000	5.1E-04	1.1E-06	1.7E-06	4.2E-06	3.2E-06	2.3E-09	2.1E-05	2.0E-09	1.3E-09
3A2	181	479	1.1E+06	2.8E-01	2.8E-01	416800	4000	3.1E-04	5.0E-06	6.3E-07	2.7E-05	6.1E-07	7.0E-10	6.8E-06	7.5E-10	5.4E-10
3A2	182	844	4.7E+06	1.2E+00	7.9E-01	416800	4000	5.0E-04	1.1E-06	1.6E-06	4.1E-06	3.0E-06	2.2E-09	2.0E-05	1.9E-09	1.3E-09
3A2	183	479	1.1E+06	2.8E-01	2.8E-01	420800	4000	3.1E-04	4.9E-06	6.0E-07	2.7E-05	6.0E-07	7.0E-10	6.3E-06	7.3E-10	5.3E-10
3A2	184	844	4.7E+06	1.2E+00	7.9E-01	420800	4000	5.0E-04	1.0E-06	1.6E-06	3.9E-06	2.8E-06	2.0E-09	1.8E-05	1.9E-09	1.3E-09
3A2	185	479	1.1E+06	2.8E-01	2.8E-01	424800	4000	3.0E-04	4.9E-06	6.1E-07	2.6E-05	5.4E-07	7.0E-10	5.9E-06	7.3E-10	5.5E-10
3A2	186	820	9.7E+03	2.9E-03	4.2E-01	424800	24000	2.0E-05	4.2E-08	6.3E-08	1.5E-07	9.7E-08	7.1E-11	6.4E-07	7.6E-11	5.6E-11
3A2	187	821	8.0E+03	2.4E-03	4.2E-01	424800	24000	1.6E-05	3.5E-08	5.2E-08	1.2E-07	8.0E-08	5.9E-11	5.3E-07	6.3E-11	4.6E-11
3A2	188	824	4.6E+03	1.4E-03	4.2E-01	424800	24000	9.2E-06	2.0E-08	3.0E-08	7.1E-08	4.6E-08	3.4E-11	3.0E-07	3.6E-11	2.6E-11
3A2	189	844	4.7E+06	1.2E+00	7.9E-01	424800	4000	4.9E-04	1.0E-06	1.5E-06	3.7E-06	2.6E-06	1.9E-09	1.7E-05	1.8E-09	1.3E-09
3A2	190	479	1.1E+06	2.8E-01	2.8E-01	428800	4000	3.0E-04	4.8E-06	6.0E-07	2.5E-05	5.1E-07	5.8E-10	5.5E-06	7.2E-10	5.5E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	191	844	4.6E+06	1.2E+00	7.9E-01	428800	4000	4.9E-04	9.7E-07	1.5E-06	3.6E-06	2.4E-06	1.8E-09	1.6E-05	1.8E-09	1.3E-09
3A2	192	479	1.1E+06	2.8E-01	2.8E-01	432800	4000	3.0E-04	4.8E-06	5.3E-07	2.5E-05	4.8E-07	5.2E-10	5.1E-06	6.6E-10	5.0E-10
3A2	193	844	4.7E+06	1.2E+00	7.9E-01	432800	4000	4.9E-04	9.5E-07	1.4E-06	3.5E-06	2.2E-06	1.6E-09	1.5E-05	1.7E-09	1.2E-09
3A2	194	479	1.1E+06	2.7E-01	2.8E-01	436800	4000	2.9E-04	4.8E-06	5.5E-07	2.5E-05	4.3E-07	5.8E-10	4.8E-06	6.7E-10	5.3E-10
3A2	195	844	4.6E+06	1.2E+00	7.9E-01	436800	4000	4.8E-04	9.4E-07	1.4E-06	3.4E-06	2.1E-06	1.5E-09	1.4E-05	1.7E-09	1.2E-09
3A2	196	479	1.1E+06	2.7E-01	2.8E-01	440800	4000	2.9E-04	4.7E-06	5.7E-07	2.4E-05	4.2E-07	4.7E-10	4.5E-06	6.9E-10	5.6E-10
3A2	197	844	4.6E+06	1.2E+00	7.9E-01	440800	4000	4.8E-04	9.3E-07	1.4E-06	3.3E-06	1.9E-06	1.4E-09	1.3E-05	1.7E-09	1.3E-09
3A2	198	479	1.0E+06	2.7E-01	2.8E-01	444800	4000	2.9E-04	4.7E-06	5.4E-07	2.4E-05	4.0E-07	4.7E-10	4.2E-06	6.6E-10	5.4E-10
3A2	199	844	4.6E+06	1.2E+00	7.9E-01	444800	4000	4.7E-04	9.2E-07	1.3E-06	3.2E-06	1.8E-06	1.3E-09	1.2E-05	1.6E-09	1.3E-09
3A2	200	479	1.0E+06	2.7E-01	2.8E-01	448800	4000	2.9E-04	4.7E-06	4.9E-07	2.4E-05	3.4E-07	3.5E-10	3.9E-06	6.2E-10	5.0E-10
3A2	201	820	9.3E+03	2.8E-03	4.2E-01	448800	20000	1.5E-05	3.4E-08	4.5E-08	1.1E-07	5.5E-08	4.1E-11	3.6E-07	5.6E-11	4.5E-11
3A2	202	821	7.7E+03	2.3E-03	4.2E-01	448800	20000	1.3E-05	2.8E-08	3.7E-08	8.9E-08	4.5E-08	3.4E-11	3.0E-07	4.6E-11	3.7E-11
3A2	203	844	4.6E+06	1.2E+00	8.0E-01	448800	4000	4.7E-04	9.2E-07	1.3E-06	3.1E-06	1.7E-06	1.3E-09	1.1E-05	1.6E-09	1.2E-09
3A2	204	479	1.0E+06	2.7E-01	2.8E-01	452800	4000	2.8E-04	4.7E-06	5.2E-07	2.3E-05	3.9E-07	5.2E-10	3.7E-06	6.4E-10	5.3E-10
3A2	205	844	4.6E+06	1.2E+00	8.0E-01	452800	4000	4.6E-04	9.3E-07	1.3E-06	3.0E-06	1.6E-06	1.2E-09	1.0E-05	1.6E-09	1.2E-09
3A2	206	479	1.0E+06	2.7E-01	2.8E-01	456800	4000	2.8E-04	4.6E-06	5.0E-07	2.2E-05	3.1E-07	3.5E-10	3.5E-06	6.2E-10	5.2E-10
3A2	207	844	4.6E+06	1.2E+00	8.0E-01	456800	4000	4.6E-04	9.3E-07	1.2E-06	3.0E-06	1.5E-06	1.1E-09	9.7E-06	1.5E-09	1.2E-09
3A2	208	479	1.0E+06	2.6E-01	2.8E-01	460800	4000	2.8E-04	4.7E-06	4.6E-07	2.2E-05	3.0E-07	3.5E-10	3.2E-06	5.8E-10	4.9E-10
3A2	209	844	4.6E+06	1.2E+00	8.0E-01	460800	4000	4.6E-04	9.5E-07	1.2E-06	2.9E-06	1.4E-06	1.0E-09	9.0E-06	1.5E-09	1.2E-09
3A2	210	479	1.0E+06	2.6E-01	2.8E-01	464800	4000	2.8E-04	4.6E-06	4.8E-07	2.2E-05	3.0E-07	2.9E-10	3.0E-06	6.0E-10	5.2E-10
3A2	211	844	4.6E+06	1.2E+00	8.0E-01	464800	4000	4.5E-04	9.6E-07	1.2E-06	2.8E-06	1.3E-06	9.6E-10	8.4E-06	1.5E-09	1.2E-09
3A2	212	479	1.0E+06	2.6E-01	2.8E-01	468800	4000	2.7E-04	4.7E-06	4.5E-07	2.2E-05	2.8E-07	2.9E-10	2.9E-06	5.7E-10	5.0E-10
3A2	213	820	8.9E+03	2.7E-03	4.1E-01	468800	20000	1.5E-05	3.8E-08	4.0E-08	1.0E-07	3.9E-08	2.9E-11	2.6E-07	5.0E-11	4.3E-11
3A2	214	821	7.4E+03	2.2E-03	4.1E-01	468800	20000	1.2E-05	3.1E-08	3.3E-08	8.2E-08	3.2E-08	2.4E-11	2.1E-07	4.1E-11	3.5E-11
3A2	215	844	4.6E+06	1.2E+00	8.0E-01	468800	4000	4.5E-04	9.8E-07	1.1E-06	2.8E-06	1.2E-06	9.0E-10	7.9E-06	1.4E-09	1.2E-09
3A2	216	479	9.9E+05	2.6E-01	2.8E-01	472800	4000	2.7E-04	4.7E-06	4.0E-07	2.1E-05	2.7E-07	3.5E-10	2.7E-06	5.3E-10	4.6E-10
3A2	217	844	4.6E+06	1.2E+00	8.0E-01	472800	4000	4.4E-04	1.0E-06	1.1E-06	2.8E-06	1.1E-06	8.4E-10	7.3E-06	1.4E-09	1.2E-09
3A2	218	479	9.9E+05	2.6E-01	2.8E-01	476800	4000	2.7E-04	4.7E-06	4.1E-07	2.1E-05	2.4E-07	2.9E-10	2.5E-06	5.4E-10	4.8E-10
3A2	219	844	4.5E+06	1.2E+00	8.0E-01	476800	4000	4.4E-04	1.0E-06	1.1E-06	2.7E-06	1.0E-06	7.8E-10	6.8E-06	1.3E-09	1.1E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	220	479	9.8E+05	2.5E-01	2.8E-01	480800	4000	2.7E-04	4.7E-06	4.4E-07	2.1E-05	2.4E-07	2.3E-10	2.4E-06	5.7E-10	5.0E-10
3A2	221	844	4.5E+06	1.2E+00	8.0E-01	480800	4000	4.4E-04	1.1E-06	1.0E-06	2.7E-06	9.7E-07	7.4E-10	6.4E-06	1.3E-09	1.2E-09
3A2	222	479	9.7E+05	2.5E-01	2.8E-01	484800	4000	2.6E-04	4.7E-06	4.2E-07	2.1E-05	2.2E-07	1.7E-10	2.3E-06	5.5E-10	5.0E-10
3A2	223	844	4.5E+06	1.2E+00	8.0E-01	484800	4000	4.3E-04	1.1E-06	1.0E-06	2.7E-06	9.0E-07	6.9E-10	6.0E-06	1.3E-09	1.2E-09
3A2	224	479	9.6E+05	2.5E-01	2.8E-01	488800	4000	2.6E-04	4.7E-06	4.1E-07	2.0E-05	2.1E-07	2.9E-10	2.1E-06	5.4E-10	4.9E-10
3A2	225	820	8.5E+03	2.5E-03	4.1E-01	488800	24000	1.7E-05	5.4E-08	4.2E-08	1.2E-07	3.2E-08	2.5E-11	2.1E-07	5.6E-11	5.0E-11
3A2	226	821	7.1E+03	2.1E-03	4.1E-01	488800	24000	1.4E-05	4.5E-08	3.5E-08	9.6E-08	2.7E-08	2.1E-11	1.8E-07	4.6E-11	4.1E-11
3A2	227	824	4.0E+03	1.2E-03	4.1E-01	488800	24000	7.9E-06	2.6E-08	2.0E-08	5.5E-08	1.5E-08	1.2E-11	1.0E-07	2.6E-11	2.4E-11
3A2	228	844	4.5E+06	1.2E+00	8.0E-01	488800	4000	4.3E-04	1.1E-06	1.0E-06	2.7E-06	8.5E-07	6.5E-10	5.6E-06	1.3E-09	1.2E-09
3A2	229	479	9.6E+05	2.5E-01	2.8E-01	492800	4000	2.6E-04	4.7E-06	3.9E-07	2.0E-05	1.9E-07	1.2E-10	2.0E-06	5.3E-10	4.8E-10
3A2	230	844	4.5E+06	1.2E+00	8.0E-01	492800	4000	4.2E-04	1.2E-06	9.8E-07	2.7E-06	7.9E-07	6.1E-10	5.2E-06	1.3E-09	1.1E-09
3A2	231	479	9.5E+05	2.5E-01	2.8E-01	496800	4000	2.5E-04	4.9E-06	3.6E-07	2.1E-05	1.8E-07	2.3E-10	1.9E-06	4.9E-10	4.5E-10
3A2	232	844	4.5E+06	1.2E+00	8.0E-01	496800	4000	4.2E-04	1.2E-06	9.4E-07	2.7E-06	7.3E-07	5.7E-10	4.9E-06	1.2E-09	1.1E-09
3A2	233	479	9.4E+05	2.5E-01	2.8E-01	500800	4000	2.5E-04	4.9E-06	3.7E-07	2.1E-05	1.9E-07	1.7E-10	1.8E-06	5.0E-10	4.6E-10
3A2	234	844	4.5E+06	1.2E+00	8.0E-01	500800	4000	4.2E-04	1.3E-06	9.2E-07	2.7E-06	6.8E-07	5.3E-10	4.6E-06	1.2E-09	1.1E-09
3A2	235	479	9.4E+05	2.4E-01	2.8E-01	504800	4000	2.5E-04	4.9E-06	4.0E-07	2.0E-05	1.8E-07	2.3E-10	1.7E-06	5.3E-10	5.0E-10
3A2	236	844	4.5E+06	1.2E+00	8.1E-01	504800	4000	4.1E-04	1.3E-06	9.3E-07	2.7E-06	6.4E-07	5.0E-10	4.3E-06	1.2E-09	1.1E-09
3A2	237	479	9.3E+05	2.4E-01	2.8E-01	508800	4000	2.5E-04	4.9E-06	4.0E-07	2.0E-05	1.6E-07	1.2E-10	1.6E-06	5.4E-10	5.1E-10
3A2	238	844	4.4E+06	1.2E+00	8.1E-01	508800	4000	4.1E-04	1.4E-06	9.3E-07	2.7E-06	6.0E-07	4.8E-10	4.0E-06	1.2E-09	1.1E-09
3A2	239	479	9.2E+05	2.4E-01	2.8E-01	512800	4000	2.4E-04	5.0E-06	4.1E-07	2.0E-05	1.6E-07	2.3E-10	1.5E-06	5.5E-10	5.2E-10
3A2	240	820	8.2E+03	2.4E-03	4.1E-01	512800	20000	1.3E-05	5.6E-08	3.4E-08	9.9E-08	1.8E-08	1.5E-11	1.2E-07	4.6E-11	4.3E-11
3A2	241	821	6.8E+03	2.0E-03	4.1E-01	512800	20000	1.1E-05	4.7E-08	2.8E-08	8.2E-08	1.5E-08	1.2E-11	1.0E-07	3.8E-11	3.5E-11
3A2	242	844	4.4E+06	1.2E+00	8.1E-01	512800	4000	4.0E-04	1.4E-06	9.4E-07	2.7E-06	5.6E-07	4.5E-10	3.8E-06	1.3E-09	1.2E-09
3A2	243	479	9.1E+05	2.4E-01	2.8E-01	516800	4000	2.4E-04	5.0E-06	4.1E-07	2.0E-05	1.3E-07	1.2E-10	1.5E-06	5.6E-10	5.3E-10
3A2	244	844	4.4E+06	1.1E+00	8.1E-01	516800	4000	4.0E-04	1.5E-06	9.4E-07	2.7E-06	5.3E-07	4.3E-10	3.5E-06	1.3E-09	1.2E-09
3A2	245	479	9.1E+05	2.4E-01	2.8E-01	520800	3999.9	2.4E-04	5.1E-06	3.9E-07	2.0E-05	1.6E-07	1.2E-10	1.4E-06	5.3E-10	5.1E-10
3A2	246	844	4.4E+06	1.1E+00	8.1E-01	520800	3999.9	4.0E-04	1.5E-06	9.3E-07	2.7E-06	4.9E-07	4.0E-10	3.3E-06	1.3E-09	1.2E-09
3A2	247	479	9.0E+05	2.3E-01	2.8E-01	524800	4000	2.4E-04	5.2E-06	3.6E-07	2.0E-05	1.3E-07	1.2E-10	1.4E-06	5.1E-10	4.9E-10
3A2	248	844	4.4E+06	1.1E+00	8.1E-01	524800	4000	3.9E-04	1.6E-06	9.1E-07	2.8E-06	4.6E-07	3.8E-10	3.1E-06	1.2E-09	1.2E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	249	479	8.9E+05	2.3E-01	2.8E-01	528800	4000	2.4E-04	5.2E-06	3.7E-07	2.0E-05	1.3E-07	1.2E-10	1.3E-06	5.2E-10	5.0E-10
3A2	250	844	4.4E+06	1.1E+00	8.1E-01	528800	4000	3.9E-04	1.7E-06	8.9E-07	2.8E-06	4.3E-07	3.6E-10	2.9E-06	1.2E-09	1.2E-09
3A2	251	479	8.9E+05	2.3E-01	2.8E-01	532800	4000	2.3E-04	5.2E-06	3.7E-07	1.9E-05	1.0E-07	2.3E-10	1.3E-06	5.2E-10	5.0E-10
3A2	252	820	7.8E+03	2.3E-03	4.0E-01	532800	24000	1.5E-05	8.8E-08	3.8E-08	1.3E-07	1.5E-08	1.3E-11	1.0E-07	5.4E-11	5.2E-11
3A2	253	821	6.5E+03	1.9E-03	4.0E-01	532800	24000	1.2E-05	7.3E-08	3.2E-08	1.1E-07	1.3E-08	1.1E-11	8.7E-08	4.4E-11	4.3E-11
3A2	254	824	3.7E+03	1.1E-03	4.0E-01	532800	24000	7.1E-06	4.1E-08	1.8E-08	6.1E-08	7.2E-09	6.3E-12	4.9E-08	2.5E-11	2.4E-11
3A2	255	844	4.4E+06	1.1E+00	8.1E-01	532800	4000	3.9E-04	1.8E-06	8.9E-07	2.8E-06	4.0E-07	3.4E-10	2.7E-06	1.2E-09	1.2E-09
3A2	256	479	8.8E+05	2.3E-01	2.8E-01	536800	4000	2.3E-04	5.3E-06	3.5E-07	1.9E-05	1.3E-07	0.0E+00	1.2E-06	5.1E-10	4.9E-10
3A2	257	844	4.4E+06	1.1E+00	8.1E-01	536800	4000	3.8E-04	1.9E-06	8.7E-07	2.9E-06	3.7E-07	3.2E-10	2.6E-06	1.2E-09	1.2E-09
3A2	258	479	8.7E+05	2.3E-01	2.8E-01	540800	4000	2.3E-04	5.4E-06	3.8E-07	1.9E-05	1.0E-07	1.2E-10	1.2E-06	5.3E-10	5.2E-10
3A2	259	844	4.3E+06	1.1E+00	8.1E-01	540800	4000	3.8E-04	1.9E-06	8.7E-07	2.9E-06	3.5E-07	3.1E-10	2.4E-06	1.2E-09	1.2E-09
3A2	260	479	8.7E+05	2.3E-01	2.8E-01	544800	4000	2.3E-04	5.4E-06	3.8E-07	1.8E-05	1.0E-07	1.2E-10	1.1E-06	5.4E-10	5.3E-10
3A2	261	844	4.3E+06	1.1E+00	8.1E-01	544800	4000	3.8E-04	2.0E-06	8.7E-07	3.0E-06	3.2E-07	2.9E-10	2.2E-06	1.2E-09	1.2E-09
3A2	262	479	8.6E+05	2.2E-01	2.8E-01	548800	4000	2.2E-04	5.6E-06	3.3E-07	2.0E-05	1.0E-07	1.2E-10	1.1E-06	4.9E-10	4.8E-10
3A2	263	844	4.3E+06	1.1E+00	8.1E-01	548800	4000	3.7E-04	2.1E-06	8.4E-07	3.0E-06	3.0E-07	2.7E-10	2.1E-06	1.2E-09	1.2E-09
3A2	264	479	8.5E+05	2.2E-01	2.8E-01	552800	4000	2.2E-04	5.6E-06	3.5E-07	1.9E-05	8.9E-08	1.2E-10	1.1E-06	5.2E-10	5.0E-10
3A2	265	844	4.3E+06	1.1E+00	8.2E-01	552800	4000	3.7E-04	2.2E-06	8.4E-07	3.1E-06	2.8E-07	2.6E-10	2.0E-06	1.2E-09	1.2E-09
3A2	266	479	8.5E+05	2.2E-01	2.8E-01	556800	4000	2.2E-04	5.6E-06	3.7E-07	1.7E-05	1.0E-07	1.2E-10	1.0E-06	5.3E-10	5.2E-10
3A2	267	820	7.5E+03	2.2E-03	4.0E-01	556800	20000	1.2E-05	9.6E-08	3.0E-08	1.2E-07	8.4E-09	8.4E-12	6.2E-08	4.4E-11	4.3E-11
3A2	268	821	6.2E+03	1.8E-03	4.0E-01	556800	20000	9.8E-06	7.9E-08	2.5E-08	1.0E-07	7.0E-09	6.9E-12	5.1E-08	3.6E-11	3.6E-11
3A2	269	844	4.3E+06	1.1E+00	8.2E-01	556800	4000	3.6E-04	2.4E-06	8.4E-07	3.2E-06	2.6E-07	2.5E-10	1.9E-06	1.2E-09	1.2E-09
3A2	270	479	8.4E+05	2.2E-01	2.8E-01	560800	4000	2.2E-04	5.8E-06	3.4E-07	1.7E-05	7.5E-08	0.0E+00	1.0E-06	5.0E-10	5.0E-10
3A2	271	844	4.3E+06	1.1E+00	8.2E-01	560800	4000	3.6E-04	2.5E-06	8.2E-07	3.3E-06	2.4E-07	2.3E-10	1.7E-06	1.2E-09	1.2E-09
3A2	272	479	8.4E+05	2.2E-01	2.8E-01	564800	4000	2.2E-04	5.9E-06	3.3E-07	1.7E-05	8.9E-08	1.2E-10	1.0E-06	5.0E-10	4.9E-10
3A2	273	844	4.3E+06	1.1E+00	8.2E-01	564800	4000	3.6E-04	2.6E-06	8.0E-07	3.3E-06	2.2E-07	2.2E-10	1.6E-06	1.2E-09	1.1E-09
3A2	274	479	8.3E+05	2.2E-01	2.8E-01	568800	4000	2.1E-04	6.0E-06	3.6E-07	1.7E-05	7.5E-08	1.7E-10	9.9E-07	5.4E-10	5.3E-10
3A2	275	844	4.4E+06	1.1E+00	8.0E-01	568800	4000	3.6E-04	2.8E-06	8.4E-07	3.5E-06	2.1E-07	2.2E-10	1.6E-06	1.2E-09	1.2E-09
3A2	276	479	8.2E+05	2.1E-01	2.8E-01	572800	3999.9	2.1E-04	6.1E-06	3.5E-07	1.7E-05	7.5E-08	0.0E+00	9.7E-07	5.2E-10	5.2E-10
3A2	277	844	4.4E+06	1.1E+00	7.8E-01	572800	3999.9	3.5E-04	3.0E-06	8.4E-07	3.7E-06	2.0E-07	2.1E-10	1.5E-06	1.2E-09	1.2E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
3A2	278	479	8.2E+05	2.1E-01	2.8E-01	576800	4000.1	2.1E-04	6.3E-06	3.1E-07	1.8E-05	1.0E-07	1.2E-10	9.5E-07	4.8E-10	4.7E-10
3A2	279	820	7.2E+03	2.1E-03	4.0E-01	576800	20000	1.1E-05	1.3E-07	2.7E-08	1.4E-07	6.0E-09	6.4E-12	4.5E-08	4.2E-11	4.2E-11
3A2	280	821	6.0E+03	1.7E-03	4.0E-01	576800	20000	9.3E-06	1.0E-07	2.3E-08	1.2E-07	5.0E-09	5.3E-12	3.7E-08	3.5E-11	3.4E-11
3A2	281	844	4.4E+06	1.1E+00	7.9E-01	576800	4000.1	3.5E-04	3.2E-06	8.2E-07	3.8E-06	1.9E-07	2.0E-10	1.4E-06	1.2E-09	1.2E-09
3A2	282	479	8.1E+05	2.1E-01	2.8E-01	580800	3999.9	2.0E-04	6.5E-06	2.8E-07	2.0E-05	8.9E-08	0.0E+00	9.3E-07	4.5E-10	4.5E-10
3A2	283	844	4.4E+06	1.1E+00	7.9E-01	580800	3999.9	3.4E-04	3.4E-06	7.9E-07	4.0E-06	1.8E-07	1.9E-10	1.3E-06	1.2E-09	1.2E-09
3A2	284	479	8.0E+05	2.1E-01	2.8E-01	584800	4000.1	2.0E-04	6.7E-06	2.7E-07	2.0E-05	7.5E-08	1.2E-10	9.2E-07	4.4E-10	4.4E-10
3A2	285	844	4.4E+06	1.1E+00	7.9E-01	584800	4000.1	3.4E-04	3.6E-06	7.6E-07	4.1E-06	1.7E-07	1.8E-10	1.3E-06	1.2E-09	1.2E-09
3A2	286	479	8.0E+05	2.1E-01	2.8E-01	588800	3999.8	2.0E-04	6.7E-06	3.0E-07	1.8E-05	1.0E-07	0.0E+00	9.3E-07	4.7E-10	4.7E-10
3A2	287	844	4.4E+06	1.1E+00	7.9E-01	588800	3999.8	3.4E-04	3.8E-06	7.6E-07	4.3E-06	1.6E-07	1.7E-10	1.2E-06	1.2E-09	1.2E-09
3A2	288	479	7.9E+05	2.1E-01	2.8E-01	592800	4000.1	2.0E-04	6.8E-06	3.0E-07	1.7E-05	8.9E-08	1.2E-10	9.4E-07	4.8E-10	4.8E-10
3A2	289	844	4.3E+06	1.1E+00	7.9E-01	592800	4000.1	3.4E-04	4.0E-06	7.5E-07	4.4E-06	1.5E-07	1.6E-10	1.1E-06	1.2E-09	1.2E-09
3A2	290	479	7.8E+05	2.0E-01	2.8E-01	596800	8000.1	3.9E-04	1.4E-05	5.8E-07	3.4E-05	1.8E-07	1.2E-10	1.9E-06	9.3E-10	9.4E-10
3A2	291	844	4.3E+06	1.1E+00	7.9E-01	596800	4000	3.3E-04	4.2E-06	7.4E-07	4.6E-06	1.5E-07	1.5E-10	1.0E-06	1.2E-09	1.2E-09
3A2	292	844	4.3E+06	1.1E+00	7.9E-01	600800	4000.1	3.3E-04	4.4E-06	7.3E-07	4.7E-06	1.4E-07	1.5E-10	9.7E-07	1.2E-09	1.2E-09
5	1	27	1.3E+07	3.5E+00	7.5E-01	33800	3599.9	8.7E-02	3.4E-05	2.9E-07	4.6E-05	3.3E-05	3.2E-07	8.2E-06	6.4E-12	6.4E-12
5	2	997	2.9E+05	7.1E-02	1.0E+00	34500	3600	2.1E-04	4.6E-05	6.6E-07	4.4E-05	3.6E-05	1.9E-07	1.1E-05	4.5E-12	4.5E-12
5	3	998	7.4E+05	1.8E-01	9.4E-01	34500	3600	1.5E-03	3.3E-04	3.4E-06	4.1E-04	3.0E-04	2.8E-06	8.0E-05	5.7E-11	5.7E-11
5	4	27	1.1E+07	2.8E+00	5.8E-01	37400	3601.6	1.1E-01	3.2E-05	3.2E-07	7.4E-05	4.8E-05	8.2E-07	7.5E-06	1.5E-11	1.5E-11
5	5	997	5.1E+04	1.2E-02	9.6E-01	38100	3599.9	2.9E-04	1.5E-05	1.4E-07	3.2E-05	2.1E-05	3.3E-07	3.6E-06	6.2E-12	6.2E-12
5	6	998	1.0E+05	2.6E-02	9.0E-01	38100	3599.9	7.6E-04	6.6E-05	5.9E-07	1.3E-04	8.7E-05	1.4E-06	1.6E-05	2.6E-11	2.6E-11
5	7	27	1.0E+07	2.6E+00	5.1E-01	41002	3598.4	7.2E-02	7.3E-06	1.2E-07	2.2E-05	1.4E-05	2.8E-07	1.6E-06	5.3E-12	5.3E-12
5	8	997	3.7E+05	9.0E-02	9.7E-01	41700	3600	2.2E-03	2.8E-05	4.1E-07	7.9E-05	5.3E-05	9.8E-07	6.1E-06	1.9E-11	1.9E-11
5	9	998	5.7E+05	1.4E-01	9.2E-01	41700	3600	3.8E-03	8.1E-05	1.2E-06	2.4E-04	1.6E-04	2.9E-06	1.8E-05	5.7E-11	5.7E-11
5	10	27	8.2E+06	2.0E+00	4.7E-01	44600	3600.1	4.4E-02	1.1E-06	1.6E-08	3.6E-06	1.9E-06	3.7E-08	2.2E-07	7.3E-13	7.3E-13
5	11	27	8.1E+06	1.9E+00	4.8E-01	48200	3600	4.5E-02	5.0E-07	6.2E-09	1.7E-06	8.0E-07	1.5E-08	1.0E-07	3.1E-13	2.8E-13
5	12	820	8.8E+02	2.2E-04	1.0E+00	48202	21598	5.6E-07	1.7E-07	6.9E-07	2.6E-07	1.7E-07	3.5E-09	3.2E-09	6.1E-08	1.4E-09
5	13	821	7.3E+02	1.9E-04	1.0E+00	48202	21598	4.6E-07	1.5E-07	5.8E-07	2.2E-07	1.5E-07	2.9E-09	2.7E-09	5.1E-08	1.2E-09
5	14	824	4.4E+02	1.1E-04	1.0E+00	48202	21598	2.8E-07	9.2E-08	3.6E-07	1.4E-07	9.2E-08	1.8E-09	1.7E-09	3.2E-08	7.3E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5	15	27	9.7E+06	2.3E+00	5.1E-01	51800	3600	5.3E-02	4.7E-07	5.6E-09	1.6E-06	7.4E-07	1.3E-08	1.0E-07	2.8E-13	2.5E-13
5	16	27	1.0E+07	2.4E+00	5.2E-01	55400	3599.9	5.0E-02	3.5E-07	4.1E-09	1.2E-06	5.5E-07	9.5E-09	7.8E-08	2.0E-13	1.8E-13
5	17	27	1.0E+07	2.4E+00	5.3E-01	59000	3600	4.6E-02	2.5E-07	2.9E-09	9.3E-07	3.9E-07	6.7E-09	5.5E-08	1.4E-13	1.3E-13
5	18	27	1.0E+07	2.4E+00	5.4E-01	62600	3600	4.2E-02	1.7E-07	2.0E-09	7.0E-07	2.7E-07	4.7E-09	3.9E-08	9.5E-14	8.9E-14
5	19	27	1.0E+07	2.4E+00	5.5E-01	66200	3600	3.8E-02	1.3E-07	1.5E-09	5.5E-07	2.0E-07	3.4E-09	2.9E-08	6.9E-14	6.6E-14
5	20	27	1.0E+07	2.4E+00	5.6E-01	69800	3600	3.5E-02	8.8E-08	1.0E-09	4.2E-07	1.4E-07	2.4E-09	2.0E-08	4.8E-14	4.5E-14
5	21	820	7.0E+02	2.2E-04	1.0E+00	69800	21600	5.9E-07	1.8E-08	4.2E-08	6.5E-08	6.2E-08	2.5E-11	1.0E-09	5.4E-10	5.5E-11
5	22	821	5.9E+02	1.8E-04	1.0E+00	69800	21600	4.9E-07	1.6E-08	3.5E-08	5.5E-08	5.2E-08	2.1E-11	8.8E-10	4.5E-10	4.6E-11
5	23	824	3.5E+02	1.1E-04	1.0E+00	69800	21600	3.1E-07	9.7E-09	2.2E-08	3.4E-08	3.2E-08	1.3E-11	5.5E-10	2.8E-10	2.9E-11
5	24	27	1.1E+07	2.5E+00	5.6E-01	73400	3600.1	3.2E-02	6.1E-08	7.1E-10	3.2E-07	9.5E-08	1.6E-09	1.4E-08	3.4E-14	3.2E-14
5	25	997	6.4E+04	1.5E-02	1.0E+00	74100	3600.1	1.4E-04	2.0E-08	2.4E-10	5.4E-08	3.2E-08	5.5E-10	4.6E-09	1.8E-14	1.1E-14
5	26	998	7.6E+04	1.8E-02	9.6E-01	74100	3600.1	1.9E-04	7.9E-08	9.1E-10	2.0E-07	1.2E-07	2.1E-09	1.8E-08	4.4E-14	4.1E-14
5	27	27	1.0E+07	2.4E+00	5.7E-01	77000	3600	2.8E-02	4.0E-08	6.5E-10	2.3E-07	6.1E-08	1.0E-09	8.7E-09	1.4E-13	5.4E-14
5	28	27	1.1E+07	2.5E+00	5.8E-01	80600	3600	2.7E-02	2.8E-08	4.0E-10	1.9E-07	4.3E-08	7.3E-10	6.1E-09	6.5E-14	2.8E-14
5	29	27	1.1E+07	2.5E+00	5.8E-01	84200	3200.1	2.2E-02	1.5E-08	2.0E-10	1.3E-07	2.3E-08	3.9E-10	3.3E-09	2.6E-14	1.3E-14
5	30	27	1.1E+07	2.5E+00	5.9E-01	87400	3999.9	2.5E-02	8.4E-09	1.1E-10	1.2E-07	1.3E-08	2.3E-10	1.9E-09	1.3E-14	6.6E-15
5	31	27	1.1E+07	2.5E+00	5.9E-01	91400	4000	2.3E-02	5.3E-09	6.7E-11	9.3E-08	8.1E-09	1.4E-10	1.2E-09	8.6E-15	5.2E-15
5	32	820	4.3E+02	1.8E-04	1.0E+00	91400	22000	5.4E-07	3.2E-08	1.2E-08	1.4E-07	7.1E-08	7.0E-12	3.5E-09	1.7E-10	4.8E-11
5	33	821	3.7E+02	1.5E-04	1.0E+00	91400	22000	4.6E-07	2.7E-08	9.8E-09	1.2E-07	6.1E-08	6.0E-12	3.0E-09	1.4E-10	4.1E-11
5	34	824	2.2E+02	9.1E-05	1.0E+00	91400	22000	2.9E-07	1.7E-08	6.2E-09	7.4E-08	3.8E-08	3.8E-12	1.9E-09	8.9E-11	2.6E-11
5	35	997	6.7E+04	1.6E-02	1.0E+00	92400	2999.9	7.5E-05	2.8E-09	3.7E-11	8.5E-09	4.3E-09	7.5E-11	6.3E-10	7.9E-15	3.3E-15
5	36	998	8.0E+04	1.9E-02	1.0E+00	92400	2999.9	1.0E-04	7.5E-09	9.7E-11	2.1E-08	1.2E-08	2.0E-10	1.7E-09	1.1E-14	5.9E-15
5	37	27	1.0E+07	2.4E+00	6.0E-01	95400	3000.1	1.5E-02	4.1E-09	3.8E-11	6.9E-08	4.7E-09	7.3E-11	6.2E-10	2.5E-14	2.1E-14
5	38	27	1.1E+07	2.5E+00	6.1E-01	98400	4000	1.8E-02	3.1E-09	3.2E-11	6.8E-08	3.9E-09	6.5E-11	5.5E-10	1.3E-14	1.1E-14
5	39	27	1.1E+07	2.5E+00	6.1E-01	102400	3000	1.3E-02	1.1E-09	1.3E-11	3.9E-08	1.6E-09	2.6E-11	2.2E-10	3.7E-15	2.8E-15
5	40	27	1.1E+07	2.5E+00	6.2E-01	105400	4000	1.5E-02	1.0E-09	1.2E-11	4.2E-08	1.4E-09	2.5E-11	2.1E-10	3.2E-15	2.3E-15
5	41	27	1.1E+07	2.5E+00	6.1E-01	109400	3999.9	1.4E-02	2.5E-09	1.3E-11	5.9E-08	1.8E-09	1.7E-11	1.5E-10	1.0E-14	9.2E-15
5	42	998	6.9E+04	1.7E-02	1.0E+00	110400	2999.9	5.5E-05	1.5E-09	1.7E-11	6.3E-09	2.2E-09	3.6E-11	3.1E-10	5.3E-15	3.9E-15
5	43	27	1.1E+07	2.5E+00	6.3E-01	113400	3000.1	9.5E-03	3.3E-09	1.1E-11	6.1E-08	1.8E-09	9.8E-12	9.6E-11	1.3E-14	1.2E-14

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5	44	820	2.0E+02	1.2E-04	1.0E+00	113400	21000	3.7E-07	3.5E-08	1.4E-08	2.3E-07	6.3E-08	4.7E-12	4.4E-09	9.4E-11	3.3E-11
5	45	821	1.7E+02	1.1E-04	1.0E+00	113400	21000	3.2E-07	3.0E-08	1.2E-08	2.0E-07	5.4E-08	4.0E-12	3.8E-09	8.0E-11	2.8E-11
5	46	824	1.1E+02	6.4E-05	1.0E+00	113400	21000	2.0E-07	1.9E-08	7.8E-09	1.3E-07	3.4E-08	2.5E-12	2.4E-09	5.1E-11	1.8E-11
5	47	27	1.1E+07	2.5E+00	6.3E-01	116400	4000	1.2E-02	1.5E-09	6.4E-12	4.0E-08	9.6E-10	7.4E-12	6.7E-11	6.1E-15	5.5E-15
5	48	27	1.1E+07	2.5E+00	6.4E-01	120400	3000	7.9E-03	5.3E-10	2.8E-12	2.0E-08	3.9E-10	3.8E-12	3.3E-11	2.3E-15	1.9E-15
5	49	27	1.1E+07	2.5E+00	6.6E-01	123400	4000.1	9.6E-03	4.0E-09	2.5E-11	6.9E-08	2.3E-09	3.8E-12	5.1E-11	1.2E-14	1.2E-14
5	50	27	1.1E+07	2.5E+00	6.6E-01	127400	3999.9	8.7E-03	3.1E-09	2.0E-11	5.6E-08	1.8E-09	2.2E-12	3.3E-11	9.6E-15	8.9E-15
5	51	27	1.1E+07	2.5E+00	6.6E-01	131400	2999.9	6.0E-03	6.3E-10	4.0E-12	1.7E-08	3.9E-10	8.0E-13	1.1E-11	2.1E-15	1.9E-15
5	52	27	1.1E+07	2.5E+00	6.7E-01	134400	4000	7.3E-03	4.8E-10	2.9E-12	1.5E-08	2.8E-10	9.1E-13	7.3E-12	1.7E-15	1.5E-15
5	53	820	2.2E+02	1.5E-04	9.7E-01	134400	22000	4.7E-07	6.2E-08	5.0E-08	2.9E-07	1.4E-07	1.3E-11	1.1E-08	1.1E-10	5.4E-11
5	54	821	1.9E+02	1.3E-04	9.7E-01	134400	22000	4.1E-07	5.4E-08	4.3E-08	2.6E-07	1.2E-07	1.1E-11	9.7E-09	9.8E-11	4.7E-11
5	55	824	1.1E+02	7.9E-05	9.8E-01	134400	22000	2.6E-07	3.4E-08	2.7E-08	1.6E-07	7.9E-08	7.0E-12	6.2E-09	6.2E-11	3.0E-11
5	56	27	1.1E+07	2.5E+00	6.7E-01	138400	3000.1	5.0E-03	2.4E-10	1.6E-12	8.7E-09	1.5E-10	3.4E-13	5.5E-12	9.7E-16	7.9E-16
5	57	27	1.1E+07	2.5E+00	6.7E-01	141400	4000	6.1E-03	2.4E-10	1.6E-12	9.2E-09	1.4E-10	3.4E-13	3.6E-12	1.1E-15	8.4E-16
5	58	27	1.1E+07	2.5E+00	6.8E-01	145400	4000.1	5.5E-03	1.6E-10	1.3E-12	7.1E-09	9.5E-11	2.3E-13	3.6E-12	1.0E-15	7.0E-16
5	59	27	1.1E+07	2.6E+00	6.9E-01	149400	2999.9	3.8E-03	2.3E-09	4.9E-11	5.0E-09	8.2E-09	2.9E-11	6.2E-10	2.7E-14	2.6E-14
5	60	27	1.1E+07	2.6E+00	6.9E-01	152400	4000	4.7E-03	1.1E-08	1.8E-10	8.2E-09	3.3E-08	2.0E-10	3.0E-09	1.9E-13	1.9E-13
5	61	27	1.1E+07	2.6E+00	7.0E-01	156400	3000.1	3.2E-03	1.2E-08	2.5E-10	6.1E-09	3.6E-08	2.0E-10	3.3E-09	2.5E-13	2.5E-13
5	62	820	2.6E+02	1.8E-04	9.2E-01	156400	20400	5.2E-07	5.9E-08	5.4E-08	2.4E-07	2.3E-07	1.6E-11	1.1E-08	1.2E-10	7.1E-11
5	63	821	2.2E+02	1.5E-04	9.2E-01	156400	20400	4.5E-07	5.1E-08	4.7E-08	2.1E-07	2.0E-07	1.4E-11	9.8E-09	1.0E-10	6.2E-11
5	64	824	1.4E+02	9.3E-05	9.3E-01	156400	20400	2.9E-07	3.2E-08	3.0E-08	1.3E-07	1.3E-07	8.9E-12	6.3E-09	6.6E-11	3.9E-11
5	65	27	1.1E+07	2.7E+00	7.0E-01	159400	3999.9	3.9E-03	1.9E-08	3.4E-10	6.8E-09	5.9E-08	2.2E-10	5.3E-09	4.6E-13	4.6E-13
5	66	27	1.1E+07	2.7E+00	7.0E-01	163400	4000.1	3.5E-03	2.2E-08	3.4E-10	5.3E-09	7.0E-08	1.6E-10	6.1E-09	5.7E-13	5.7E-13
5	67	27	1.1E+07	2.7E+00	7.1E-01	167400	2999.9	2.4E-03	1.8E-08	2.6E-10	3.3E-09	6.1E-08	9.2E-11	4.9E-09	4.8E-13	4.8E-13
5	68	27	1.1E+07	2.7E+00	7.1E-01	170400	2399.9	1.8E-03	1.5E-08	2.1E-10	2.2E-09	5.7E-08	5.9E-11	4.0E-09	4.1E-13	4.1E-13
5	69	27	1.1E+07	2.7E+00	7.1E-01	172800	4000.2	2.8E-03	2.5E-08	3.5E-10	3.1E-09	1.1E-07	7.4E-11	6.9E-09	7.3E-13	7.3E-13
5	70	27	1.1E+07	2.7E+00	7.2E-01	176800	3999.8	2.5E-03	2.6E-08	3.6E-10	2.5E-09	1.4E-07	5.1E-11	7.1E-09	7.7E-13	7.7E-13
5	71	820	2.6E+02	1.7E-04	8.8E-01	176800	24000	6.3E-07	3.0E-08	2.8E-08	1.2E-07	2.1E-07	8.1E-12	5.7E-09	7.7E-11	5.4E-11
5	72	821	2.2E+02	1.5E-04	8.8E-01	176800	24000	5.4E-07	2.6E-08	2.5E-08	1.1E-07	1.8E-07	7.0E-12	5.0E-09	6.7E-11	4.7E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5	73	824	1.4E+02	9.0E-05	8.8E-01	176800	24000	3.5E-07	1.6E-08	1.6E-08	6.7E-08	1.2E-07	4.5E-12	3.2E-09	4.3E-11	3.0E-11
5	74	27	1.1E+07	2.7E+00	7.2E-01	180800	4000.1	2.2E-03	2.6E-08	4.2E-10	2.2E-09	1.9E-07	3.4E-11	7.2E-09	8.0E-13	8.0E-13
5	75	27	1.1E+07	2.7E+00	7.2E-01	184800	3999.9	2.0E-03	2.6E-08	6.5E-10	1.8E-09	2.3E-07	2.2E-11	7.1E-09	8.2E-13	8.3E-13
5	76	27	1.1E+07	2.7E+00	7.2E-01	188800	4000.2	1.8E-03	2.5E-08	8.0E-10	1.5E-09	2.3E-07	1.4E-11	7.0E-09	8.4E-13	8.5E-13
5	77	27	1.1E+07	2.7E+00	7.3E-01	192800	4000	1.6E-03	2.5E-08	9.2E-10	1.3E-09	2.1E-07	9.5E-12	6.9E-09	8.6E-13	8.7E-13
5	78	27	1.1E+07	2.7E+00	7.3E-01	196800	3999.9	1.4E-03	2.0E-08	1.0E-09	1.1E-09	2.1E-07	5.8E-12	5.6E-09	8.7E-13	8.9E-13
5	79	27	1.1E+07	2.7E+00	7.3E-01	200800	3999.9	1.3E-03	9.2E-09	1.4E-09	2.9E-09	2.1E-07	3.6E-12	2.5E-09	8.8E-13	8.9E-13
5	80	820	2.4E+02	1.6E-04	8.4E-01	200800	20000	5.0E-07	8.6E-09	1.1E-08	3.6E-08	1.6E-07	2.4E-12	6.1E-06	4.3E-11	3.6E-11
5	81	821	2.1E+02	1.3E-04	8.4E-01	200800	20000	4.4E-07	7.4E-09	9.3E-09	3.1E-08	1.4E-07	2.1E-12	5.5E-06	3.7E-11	3.2E-11
5	82	824	1.3E+02	8.2E-05	8.5E-01	200800	20000	2.8E-07	4.7E-09	5.9E-09	2.0E-08	8.7E-08	1.3E-12	3.5E-06	2.4E-11	2.0E-11
5	83	27	1.1E+07	2.7E+00	7.3E-01	204800	4000.1	1.2E-03	5.1E-09	1.9E-09	3.1E-08	2.4E-07	2.4E-12	1.4E-09	9.4E-13	9.6E-13
5	84	27	1.1E+07	2.7E+00	7.4E-01	208800	3999.9	1.1E-03	3.4E-09	2.5E-09	1.5E-08	2.4E-07	1.6E-12	1.0E-09	9.9E-13	1.0E-12
5	85	27	1.1E+07	2.7E+00	7.5E-01	212800	4000.1	9.3E-04	2.3E-09	3.0E-09	9.3E-09	2.4E-07	1.0E-12	1.0E-09	1.0E-12	1.0E-12
5	86	27	1.1E+07	2.7E+00	7.5E-01	216800	3999.9	8.4E-04	1.4E-09	3.0E-09	6.9E-09	2.5E-07	5.7E-13	2.5E-06	9.3E-13	9.4E-13
5	87	27	1.1E+07	2.7E+00	7.5E-01	220800	4000	7.5E-04	9.7E-10	3.3E-09	5.6E-09	3.0E-07	3.4E-13	7.3E-07	9.3E-13	9.5E-13
5	88	820	2.1E+02	1.3E-04	8.3E-01	220800	20000	4.4E-07	6.7E-10	2.9E-09	3.3E-09	1.9E-08	1.8E-12	3.9E-06	1.4E-11	1.3E-11
5	89	821	1.8E+02	1.1E-04	8.3E-01	220800	20000	3.8E-07	5.9E-10	2.6E-09	2.9E-09	1.7E-08	1.6E-12	3.5E-06	1.2E-11	1.2E-11
5	90	824	1.1E+02	6.8E-05	8.3E-01	220800	20000	2.4E-07	3.8E-10	1.6E-09	1.8E-09	1.1E-08	1.0E-12	2.2E-06	7.6E-12	7.4E-12
5	91	27	1.1E+07	2.7E+00	7.5E-01	224800	4000.1	6.7E-04	9.1E-10	4.0E-09	4.5E-09	3.7E-07	3.4E-13	3.1E-07	1.1E-12	1.1E-12
5	92	27	1.1E+07	2.7E+00	7.5E-01	228800	4000.1	6.0E-04	9.2E-10	4.5E-09	3.7E-09	4.3E-07	2.3E-13	1.8E-07	1.2E-12	1.2E-12
5	93	27	1.1E+07	2.6E+00	7.6E-01	232800	3999.9	5.4E-04	9.4E-10	4.2E-09	2.9E-09	4.3E-07	2.3E-13	1.2E-07	1.0E-12	1.0E-12
5	94	27	1.1E+07	2.6E+00	7.6E-01	236800	4000.1	4.8E-04	9.7E-10	4.4E-09	2.4E-09	5.0E-07	2.3E-13	7.9E-08	1.0E-12	1.1E-12
5	95	27	1.1E+07	2.6E+00	7.6E-01	240800	3999.9	4.3E-04	1.0E-09	4.2E-09	1.9E-09	4.1E-07	3.4E-13	5.4E-08	1.0E-12	1.1E-12
5	96	820	1.6E+02	1.0E-04	8.2E-01	240800	18400	3.2E-07	1.2E-10	4.9E-09	8.7E-10	2.6E-09	4.1E-12	5.2E-07	2.2E-11	2.3E-11
5	97	821	1.4E+02	8.5E-05	8.2E-01	240800	18400	2.8E-07	1.0E-10	4.2E-09	7.5E-10	2.2E-09	3.5E-12	4.5E-07	1.9E-11	1.9E-11
5	98	824	8.2E+01	5.1E-05	8.3E-01	240800	18400	1.7E-07	6.5E-11	2.6E-09	4.7E-10	1.4E-09	2.2E-12	2.8E-07	1.2E-11	1.2E-11
5	99	27	1.1E+07	2.6E+00	7.6E-01	244800	3999.9	3.8E-04	1.0E-09	3.9E-09	1.5E-09	2.3E-07	2.3E-13	3.7E-08	1.0E-12	1.0E-12
5	100	27	1.1E+07	2.6E+00	7.7E-01	248800	4000.1	3.4E-04	1.1E-09	3.4E-09	1.2E-09	1.4E-07	2.3E-13	2.6E-08	9.4E-13	9.5E-13
5	101	27	1.1E+07	2.6E+00	7.7E-01	252800	6400	4.8E-04	1.7E-09	5.2E-09	1.5E-09	1.3E-07	2.3E-13	2.6E-08	1.4E-12	1.4E-12

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5B	1	995	2.2E+07	5.7E+00	7.4E-01	9760	3640	1.7E-01	8.2E-02	7.6E-04	1.0E-01	9.1E-02	1.0E-03	2.0E-02	1.9E-08	1.9E-08
5B	2	998	1.1E+06	2.7E-01	9.3E-01	11000	3600	4.3E-03	1.4E-03	1.3E-05	1.4E-03	1.2E-03	1.2E-05	3.5E-04	2.2E-10	2.2E-10
5B	3	820	6.9E+02	1.7E-04	1.1E+00	11390	21610	6.3E-07	1.3E-07	1.1E-06	2.5E-07	2.2E-07	8.9E-09	9.2E-09	1.8E-07	4.7E-09
5B	4	821	5.8E+02	1.4E-04	1.1E+00	11390	21610	5.2E-07	1.1E-07	8.9E-07	2.1E-07	1.9E-07	7.5E-09	7.7E-09	1.5E-07	4.0E-09
5B	5	824	3.5E+02	8.7E-05	1.1E+00	11390	21610	3.2E-07	6.8E-08	5.5E-07	1.3E-07	1.2E-07	4.7E-09	4.8E-09	9.5E-08	2.5E-09
5B	6	997	8.8E+05	2.2E-01	9.6E-01	11390	3610	2.3E-03	8.8E-04	8.1E-06	8.2E-04	6.7E-04	6.4E-06	2.2E-04	1.2E-10	1.2E-10
5B	7	995	2.7E+06	7.3E-01	8.1E-01	13400	3600	2.1E-02	5.6E-03	1.1E-04	9.5E-03	9.0E-03	1.4E-04	1.4E-03	2.6E-09	2.6E-09
5B	8	998	4.1E+04	1.0E-02	9.3E-01	14600	3600	3.1E-04	2.6E-05	5.3E-07	4.2E-05	3.9E-05	5.9E-07	6.3E-06	1.1E-11	1.1E-11
5B	9	995	8.5E+06	2.2E+00	9.1E-01	17000	3600	5.8E-02	2.3E-03	1.0E-04	6.5E-03	5.4E-03	1.2E-04	5.2E-04	2.3E-09	2.3E-09
5B	10	998	4.3E+05	1.1E-01	9.7E-01	18200	3600	3.0E-03	6.6E-05	2.0E-06	1.3E-04	1.1E-04	3.5E-06	1.6E-05	6.4E-11	6.5E-11
5B	11	997	4.0E+05	9.8E-02	9.9E-01	18600	3600	2.6E-03	5.2E-05	1.6E-06	1.0E-04	8.9E-05	2.7E-06	1.3E-05	5.1E-11	5.1E-11
5B	12	995	3.7E+05	9.2E-02	9.9E-01	20600	3600	2.4E-03	2.4E-05	1.4E-06	8.2E-05	7.6E-05	1.1E-06	5.1E-06	3.5E-11	2.0E-11
5B	13	995	1.6E+06	4.0E-01	1.0E+00	24200	3600	1.0E-02	5.2E-05	3.2E-06	1.9E-04	1.7E-04	2.2E-06	1.1E-05	2.4E-10	4.8E-11
5B	14	995	2.2E+06	5.3E-01	1.0E+00	27800	3600.1	1.3E-02	3.7E-05	2.2E-06	1.3E-04	1.2E-04	1.6E-06	7.8E-06	2.0E-10	3.4E-11
5B	15	995	2.3E+06	5.6E-01	1.0E+00	31400	3599.9	1.4E-02	2.1E-05	1.3E-06	7.5E-05	7.0E-05	9.1E-07	4.5E-06	1.2E-10	2.0E-11
5B	16	820	7.2E+02	2.2E-04	1.0E+00	33000	21600	1.3E-06	1.2E-08	4.2E-08	1.8E-08	5.6E-08	1.6E-10	4.3E-10	4.0E-09	1.2E-10
5B	17	821	6.0E+02	1.8E-04	1.0E+00	33000	21600	1.1E-06	1.0E-08	3.5E-08	1.5E-08	4.6E-08	1.4E-10	3.6E-10	3.3E-09	1.0E-10
5B	18	824	3.6E+02	1.1E-04	1.0E+00	33000	21600	6.9E-07	6.2E-09	2.2E-08	9.2E-09	2.9E-08	8.5E-11	2.2E-10	2.1E-09	6.3E-11
5B	19	995	2.4E+06	5.8E-01	1.0E+00	35000	3599.9	1.4E-02	1.1E-05	6.5E-07	3.9E-05	3.5E-05	4.6E-07	2.3E-06	6.2E-11	1.0E-11
5B	20	995	2.4E+06	5.9E-01	1.0E+00	38600	3600.1	1.4E-02	5.7E-06	3.4E-07	2.0E-05	1.8E-05	2.4E-07	1.2E-06	3.4E-11	5.3E-12
5B	21	995	2.5E+06	6.0E-01	1.0E+00	42200	3600	1.4E-02	3.3E-06	1.9E-07	1.2E-05	1.0E-05	1.4E-07	6.9E-07	2.0E-11	3.1E-12
5B	22	995	2.5E+06	6.1E-01	1.0E+00	45800	3600	1.3E-02	2.0E-06	1.2E-07	7.5E-06	6.4E-06	8.5E-08	4.2E-07	1.3E-11	1.9E-12
5B	23	995	2.5E+06	6.2E-01	1.0E+00	49400	3599.9	1.3E-02	1.3E-06	7.5E-08	5.0E-06	4.1E-06	5.4E-08	2.7E-07	8.3E-12	1.2E-12
5B	24	995	4.5E+06	1.1E+00	1.0E+00	53000	3600.1	2.3E-02	1.5E-06	9.4E-08	6.2E-06	4.6E-06	5.9E-08	3.0E-07	1.1E-10	4.2E-11
5B	25	998	1.4E+05	3.3E-02	9.9E-01	54200	3600.1	7.0E-04	4.2E-08	2.5E-09	1.8E-07	1.4E-07	1.8E-09	8.9E-09	3.4E-13	6.4E-14
5B	26	820	4.0E+02	1.7E-04	1.0E+00	54600	21600	1.1E-06	1.1E-08	7.8E-09	3.7E-08	2.1E-08	7.0E-12	1.1E-09	1.4E-10	2.1E-11
5B	27	821	3.4E+02	1.4E-04	1.0E+00	54600	21600	9.5E-07	9.7E-09	6.7E-09	3.2E-08	1.8E-08	6.1E-12	9.1E-10	1.2E-10	1.8E-11
5B	28	824	2.0E+02	8.6E-05	1.0E+00	54600	21600	5.9E-07	6.0E-09	4.2E-09	2.0E-08	1.1E-08	3.8E-12	5.7E-10	7.7E-11	1.1E-11
5B	29	997	1.2E+05	3.0E-02	1.0E+00	54600	3600	6.1E-04	3.6E-08	2.1E-09	1.5E-07	1.2E-07	1.5E-09	7.6E-09	2.8E-13	4.9E-14

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5B	30	995	3.9E+06	9.7E-01	9.7E-01	56600	3600	1.9E-02	1.3E-06	8.9E-08	5.7E-06	3.1E-06	3.7E-08	2.0E-07	3.7E-10	1.6E-10
5B	31	995	3.5E+06	8.7E-01	9.7E-01	60200	3599.9	1.6E-02	6.7E-07	4.4E-08	3.2E-06	1.8E-06	2.2E-08	1.1E-07	1.4E-10	6.0E-11
5B	32	995	3.3E+06	8.3E-01	9.7E-01	63800	3600.1	1.5E-02	3.4E-07	2.2E-08	1.9E-06	8.9E-07	1.1E-08	6.1E-08	6.0E-11	2.6E-11
5B	33	995	3.2E+06	7.9E-01	9.8E-01	67400	3600	1.4E-02	1.9E-07	1.2E-08	1.3E-06	5.2E-07	6.5E-09	3.2E-08	3.3E-11	1.4E-11
5B	34	995	2.1E+06	5.2E-01	1.0E+00	71000	3599.9	9.3E-03	7.5E-08	5.2E-09	7.2E-07	2.2E-07	2.6E-09	1.9E-08	1.4E-11	6.2E-12
5B	35	997	1.1E+05	2.7E-02	1.0E+00	72600	3600.1	4.6E-04	3.2E-09	2.0E-10	3.3E-08	8.1E-09	1.0E-10	5.4E-10	5.5E-13	2.4E-13
5B	36	995	4.6E+06	1.2E+00	1.0E+00	74600	3600.1	2.0E-02	7.2E-07	1.3E-08	8.4E-06	5.3E-07	4.4E-09	4.8E-08	1.2E-10	8.1E-11
5B	37	998	1.2E+05	3.0E-02	1.0E+00	75800	3600.1	5.3E-04	3.8E-09	2.4E-10	3.9E-08	9.8E-09	1.3E-10	6.7E-10	6.6E-13	2.9E-13
5B	38	820	1.8E+02	1.1E-04	9.9E-01	76200	21200	7.4E-07	1.4E-08	1.5E-09	8.2E-08	1.5E-08	1.7E-11	2.3E-09	8.3E-11	1.6E-11
5B	39	821	1.5E+02	9.3E-05	9.9E-01	76200	21200	6.4E-07	1.3E-08	1.3E-09	7.1E-08	1.3E-08	1.5E-11	2.0E-09	7.6E-11	1.4E-11
5B	40	824	9.2E+01	5.6E-05	9.9E-01	76200	21200	4.0E-07	7.9E-09	8.3E-10	4.5E-08	8.2E-09	9.5E-12	1.3E-09	4.8E-11	9.0E-12
5B	41	995	3.1E+06	7.7E-01	1.0E+00	78200	3600	1.3E-02	7.0E-07	8.1E-09	8.5E-06	3.5E-07	2.4E-09	3.5E-08	9.9E-11	7.2E-11
5B	42	995	2.5E+06	6.0E-01	1.0E+00	81800	3600	9.8E-03	2.3E-07	3.4E-09	3.1E-06	1.5E-07	8.1E-10	1.3E-08	3.4E-11	2.5E-11
5B	43	995	2.6E+06	6.3E-01	1.0E+00	85400	3999.9	1.1E-02	1.7E-07	2.4E-09	2.4E-06	9.7E-08	8.1E-10	9.3E-09	2.5E-11	1.8E-11
5B	44	995	2.6E+06	6.4E-01	1.0E+00	89400	3000.1	8.3E-03	8.2E-08	1.2E-09	1.4E-06	6.0E-08	5.8E-10	7.5E-09	1.2E-11	8.9E-12
5B	45	997	1.6E+05	3.9E-02	1.0E+00	90400	3999.9	6.4E-04	5.3E-09	7.5E-11	8.9E-08	3.2E-09	2.3E-11	2.9E-10	9.6E-13	5.3E-13
5B	46	995	5.3E+06	1.3E+00	1.0E+00	92400	4000	2.2E-02	2.0E-06	2.1E-08	2.6E-05	9.8E-07	9.3E-10	5.2E-08	1.4E-09	1.2E-10
5B	47	998	1.8E+05	4.4E-02	1.0E+00	93400	3999.9	7.6E-04	6.6E-09	9.5E-11	1.1E-07	4.1E-09	2.5E-11	3.5E-10	1.6E-12	6.6E-13
5B	48	995	2.8E+06	6.9E-01	1.0E+00	96400	3000.1	8.4E-03	1.2E-06	1.1E-08	1.6E-05	6.9E-07	3.5E-10	3.5E-08	7.2E-10	6.2E-11
5B	49	995	2.6E+06	6.4E-01	1.0E+00	99400	3999.9	1.0E-02	1.1E-06	9.8E-09	1.5E-05	6.6E-07	3.5E-10	3.0E-08	6.8E-10	5.8E-11
5B	50	995	2.6E+06	6.4E-01	1.0E+00	103400	4000	9.8E-03	6.8E-07	5.9E-09	9.1E-06	3.9E-07	3.5E-10	2.0E-08	4.1E-10	3.5E-11
5B	51	995	2.6E+06	6.4E-01	1.0E+00	107400	3000	7.2E-03	3.7E-07	3.4E-09	4.9E-06	2.1E-07	1.2E-10	7.5E-09	2.1E-10	1.8E-11
5B	52	995	2.6E+06	6.4E-01	1.0E+00	110400	4000	9.4E-03	3.3E-07	2.8E-09	4.8E-06	2.0E-07	1.2E-10	1.1E-08	2.1E-10	1.8E-11
5B	53	995	2.6E+06	6.5E-01	1.0E+00	114400	3000.1	7.0E-03	1.9E-07	1.6E-09	2.8E-06	1.0E-07	0.0E+00	5.6E-09	1.1E-10	9.8E-12
5B	54	995	2.6E+06	6.5E-01	1.0E+00	117400	4000	9.1E-03	1.9E-07	1.7E-09	2.9E-06	1.2E-07	0.0E+00	5.6E-09	1.1E-10	9.7E-12
5B	55	820	7.6E+01	1.1E-04	9.3E-01	119400	22000	8.1E-07	7.2E-09	2.2E-08	1.3E-08	2.5E-08	1.0E-12	1.8E-09	2.2E-11	1.3E-11
5B	56	821	6.5E+01	9.3E-05	9.3E-01	119400	22000	6.9E-07	6.1E-09	1.9E-08	1.1E-08	2.2E-08	8.8E-13	1.5E-09	1.9E-11	1.1E-11
5B	57	824	3.8E+01	5.5E-05	9.3E-01	119400	22000	4.3E-07	3.7E-09	1.2E-08	6.6E-09	1.4E-08	5.4E-13	9.2E-10	1.2E-11	7.1E-12
5B	58	995	2.6E+06	6.5E-01	1.0E+00	121400	4000	8.9E-03	1.3E-07	1.0E-09	2.2E-06	6.7E-08	2.3E-10	1.9E-09	8.1E-11	7.0E-12

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5B	59	995	2.6E+06	6.5E-01	1.0E+00	125400	3000	6.5E-03	8.9E-08	8.1E-10	1.3E-06	5.2E-08	0.0E+00	3.7E-09	4.6E-11	3.9E-12
5B	60	995	2.6E+06	6.5E-01	1.0E+00	128400	4000	8.5E-03	8.2E-08	5.8E-10	1.4E-06	3.7E-08	0.0E+00	0.0E+00	4.7E-11	4.0E-12
5B	61	995	2.6E+06	6.5E-01	1.0E+00	132400	3000	6.3E-03	3.0E-08	4.7E-10	9.1E-07	2.2E-08	1.2E-10	3.7E-09	2.7E-11	2.3E-12
5B	62	995	2.6E+06	6.5E-01	1.0E+00	135400	4000.1	8.2E-03	4.5E-08	3.5E-10	1.0E-06	3.0E-08	0.0E+00	1.9E-09	2.8E-11	2.4E-12
5B	63	995	2.7E+06	6.5E-01	1.0E+00	139400	3999.8	8.0E-03	3.7E-08	3.5E-10	8.6E-07	2.2E-08	0.0E+00	1.9E-09	2.1E-11	1.8E-12
5B	64	820	1.3E+02	1.7E-04	8.9E-01	141400	21000	1.2E-06	4.9E-09	4.0E-08	8.7E-09	5.9E-08	5.9E-13	1.3E-09	2.7E-11	2.3E-11
5B	65	821	1.1E+02	1.5E-04	8.9E-01	141400	21000	1.0E-06	4.2E-09	3.5E-08	7.5E-09	5.1E-08	5.1E-13	1.1E-09	2.4E-11	2.0E-11
5B	66	824	6.6E+01	8.9E-05	8.9E-01	141400	21000	6.5E-07	2.6E-09	2.2E-08	4.7E-09	3.2E-08	3.2E-13	6.8E-10	1.5E-11	1.2E-11
5B	67	995	2.7E+06	6.5E-01	1.0E+00	143400	3000.1	5.9E-03	2.2E-08	2.3E-10	5.7E-07	1.5E-08	0.0E+00	0.0E+00	1.2E-11	1.1E-12
5B	68	995	2.7E+06	6.5E-01	1.0E+00	146400	4000	7.7E-03	1.5E-08	2.3E-10	6.8E-07	1.5E-08	0.0E+00	0.0E+00	1.3E-11	1.1E-12
5B	69	995	4.6E+06	1.2E+00	1.0E+00	150400	2999.9	9.8E-03	4.5E-08	1.1E-07	8.2E-07	7.0E-06	0.0E+00	1.9E-09	5.6E-11	4.5E-11
5B	70	995	3.8E+06	9.4E-01	1.0E+00	153400	4000	1.1E-02	3.7E-08	1.5E-07	8.6E-07	1.2E-05	0.0E+00	5.6E-09	9.0E-11	7.9E-11
5B	71	995	4.8E+06	1.2E+00	1.0E+00	157400	4000	1.3E-02	1.2E-07	4.9E-07	1.0E-06	5.5E-05	0.0E+00	3.2E-08	3.9E-10	3.9E-10
5B	72	995	4.5E+06	1.1E+00	1.0E+00	161400	3000.1	8.6E-03	1.0E-07	3.3E-07	6.4E-07	4.0E-05	0.0E+00	2.8E-08	2.9E-10	2.9E-10
5B	73	820	1.3E+02	1.6E-04	8.5E-01	162400	22400	1.3E-06	2.2E-09	1.7E-08	4.3E-09	5.8E-08	1.4E-12	1.4E-05	2.5E-11	2.4E-11
5B	74	821	1.1E+02	1.4E-04	8.6E-01	162400	22400	1.1E-06	2.0E-09	1.5E-08	3.7E-09	5.1E-08	1.2E-12	1.3E-05	2.2E-11	2.1E-11
5B	75	824	6.6E+01	8.3E-05	8.6E-01	162400	22400	6.8E-07	1.2E-09	9.2E-09	2.4E-09	3.2E-08	7.7E-13	8.0E-06	1.4E-11	1.3E-11
5B	76	995	3.8E+06	9.6E-01	1.0E+00	164400	3999.9	9.4E-03	1.0E-07	4.1E-07	6.6E-07	5.4E-05	0.0E+00	7.1E-08	4.1E-10	4.1E-10
5B	77	995	4.6E+06	1.2E+00	1.0E+00	168400	3000.1	8.4E-03	1.0E-07	3.3E-07	5.7E-07	4.6E-05	0.0E+00	2.8E-06	3.3E-10	3.4E-10
5B	78	995	4.4E+06	1.1E+00	1.0E+00	171400	5399.9	1.4E-02	2.3E-07	7.6E-07	9.2E-07	1.0E-04	0.0E+00	8.5E-05	7.6E-10	7.7E-10
5B	79	995	3.4E+06	8.7E-01	9.7E-01	176800	4000.2	7.7E-03	1.2E-07	4.0E-07	5.1E-07	5.6E-05	0.0E+00	4.1E-05	3.6E-10	3.7E-10
5B	80	995	3.4E+06	8.8E-01	1.0E+00	180800	3999.8	7.4E-03	9.7E-08	4.0E-07	4.8E-07	5.8E-05	0.0E+00	3.0E-05	3.1E-10	3.2E-10
5B	81	820	1.2E+02	1.5E-04	8.4E-01	184800	20000	1.1E-06	3.2E-10	5.7E-09	2.3E-09	2.2E-08	4.2E-12	4.1E-06	2.2E-11	2.3E-11
5B	82	821	1.1E+02	1.3E-04	8.4E-01	184800	20000	9.1E-07	2.7E-10	4.8E-09	2.0E-09	1.9E-08	3.6E-12	3.5E-06	1.9E-11	2.0E-11
5B	83	824	6.4E+01	7.6E-05	8.5E-01	184800	20000	5.7E-07	1.7E-10	3.0E-09	1.2E-09	1.2E-08	2.2E-12	2.2E-06	1.2E-11	1.2E-11
5B	84	995	3.4E+06	8.7E-01	1.0E+00	184800	4000.1	7.2E-03	8.9E-08	2.9E-07	5.0E-07	4.8E-05	1.2E-10	1.9E-05	2.3E-10	2.3E-10
5B	85	995	3.2E+06	8.2E-01	1.0E+00	188800	4000.1	6.6E-03	1.0E-07	2.9E-07	4.5E-07	5.3E-05	0.0E+00	1.6E-05	2.2E-10	2.2E-10
5B	86	995	3.1E+06	8.1E-01	1.0E+00	192800	3999.8	6.3E-03	1.3E-07	3.4E-07	4.4E-07	6.8E-05	0.0E+00	1.3E-05	2.1E-10	2.2E-10
5B	87	995	3.1E+06	8.1E-01	1.0E+00	196800	4000.1	6.1E-03	1.5E-07	4.1E-07	4.5E-07	8.3E-05	0.0E+00	1.1E-05	2.1E-10	2.2E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5B	88	995	3.1E+06	8.1E-01	1.0E+00	200800	4000.1	6.0E-03	1.9E-07	4.7E-07	4.5E-07	9.5E-05	1.2E-10	9.5E-06	2.1E-10	2.2E-10
5B	89	820	1.2E+02	1.4E-04	8.4E-01	204800	24000	1.2E-06	1.8E-10	1.0E-08	2.5E-09	1.2E-08	1.0E-11	2.1E-06	4.8E-11	5.0E-11
5B	90	821	1.0E+02	1.2E-04	8.4E-01	204800	24000	1.0E-06	1.6E-10	8.8E-09	2.1E-09	1.0E-08	8.9E-12	1.8E-06	4.1E-11	4.2E-11
5B	91	824	6.3E+01	7.0E-05	8.4E-01	204800	24000	6.4E-07	9.8E-11	5.5E-09	1.3E-09	6.5E-09	5.5E-12	1.1E-06	2.6E-11	2.6E-11
5B	92	995	3.1E+06	8.1E-01	1.0E+00	204800	4000	5.8E-03	1.9E-07	5.2E-07	4.5E-07	9.5E-05	1.2E-10	8.1E-06	2.2E-10	2.2E-10
5B	93	995	3.1E+06	8.1E-01	1.0E+00	208800	4000	5.6E-03	2.2E-07	5.7E-07	4.5E-07	8.5E-05	0.0E+00	6.9E-06	2.1E-10	2.2E-10
5B	94	995	3.1E+06	8.1E-01	1.0E+00	212800	3999.9	5.4E-03	2.5E-07	6.3E-07	4.4E-07	7.3E-05	1.2E-10	5.9E-06	2.1E-10	2.2E-10
5B	95	995	3.2E+06	8.3E-01	1.0E+00	216800	4000	5.4E-03	2.7E-07	6.8E-07	4.5E-07	6.4E-05	0.0E+00	5.1E-06	2.1E-10	2.2E-10
5B	96	995	3.1E+06	8.0E-01	1.0E+00	220800	4000.1	5.0E-03	2.8E-07	7.0E-07	4.3E-07	5.4E-05	0.0E+00	4.2E-06	2.0E-10	2.1E-10
5B	97	995	3.1E+06	8.1E-01	1.0E+00	224800	3999.9	4.9E-03	3.1E-07	7.2E-07	4.2E-07	4.8E-05	0.0E+00	3.6E-06	2.0E-10	2.1E-10
5B	98	820	1.2E+02	1.3E-04	8.4E-01	228800	20000	9.3E-07	1.3E-10	1.2E-08	1.9E-09	6.6E-09	1.1E-11	1.1E-06	5.6E-11	5.7E-11
5B	99	821	1.0E+02	1.1E-04	8.4E-01	228800	20000	7.9E-07	1.1E-10	9.8E-09	1.6E-09	5.7E-09	9.7E-12	9.8E-07	4.7E-11	4.9E-11
5B	100	824	6.1E+01	6.5E-05	8.4E-01	228800	20000	4.9E-07	6.8E-11	6.1E-09	1.0E-09	3.5E-09	6.1E-12	6.1E-07	3.0E-11	3.0E-11
5B	101	995	3.3E+06	8.6E-01	1.0E+00	228800	4000	5.1E-03	3.4E-07	7.5E-07	4.5E-07	4.5E-05	0.0E+00	3.3E-06	2.1E-10	2.2E-10
5B	102	995	3.2E+06	8.4E-01	1.0E+00	232800	4000	4.8E-03	3.5E-07	7.3E-07	4.3E-07	3.6E-05	0.0E+00	2.9E-06	2.1E-10	2.2E-10
5B	103	995	3.2E+06	8.4E-01	1.0E+00	236800	4000	4.7E-03	4.0E-07	7.6E-07	4.2E-07	2.9E-05	0.0E+00	2.6E-06	2.1E-10	2.2E-10
5B	104	995	3.2E+06	8.3E-01	1.0E+00	240800	3999.9	4.4E-03	4.0E-07	7.6E-07	4.2E-07	2.4E-05	2.3E-10	2.3E-06	2.1E-10	2.2E-10
5B	105	995	3.5E+06	9.1E-01	1.0E+00	244800	4000	4.7E-03	4.5E-07	8.5E-07	4.5E-07	2.2E-05	2.3E-10	2.3E-06	2.3E-10	2.3E-10
5B	106	820	1.1E+02	1.2E-04	8.3E-01	248800	10400	4.6E-07	6.7E-11	6.5E-09	9.4E-10	2.7E-09	6.0E-12	4.7E-07	3.2E-11	3.2E-11
5B	107	821	9.7E+01	1.0E-04	8.3E-01	248800	10400	3.9E-07	5.7E-11	5.5E-09	8.0E-10	2.3E-09	5.1E-12	4.0E-07	2.7E-11	2.8E-11
5B	108	824	5.9E+01	6.1E-05	8.3E-01	248800	10400	2.4E-07	3.6E-11	3.5E-09	5.0E-10	1.5E-09	3.2E-12	2.5E-07	1.7E-11	1.7E-11
5B	109	995	3.5E+06	9.2E-01	1.0E+00	248800	4000	4.6E-03	5.4E-07	8.3E-07	4.3E-07	1.9E-05	0.0E+00	2.3E-06	2.5E-10	2.6E-10
5B	110	995	3.2E+06	8.4E-01	1.0E+00	252800	6400.1	6.5E-03	8.8E-07	1.3E-06	6.3E-07	2.4E-05	0.0E+00	3.5E-06	4.1E-10	4.3E-10
5D	1	995	2.1E+07	5.6E+00	6.9E-01	9840	3628.3	1.8E-01	1.1E-01	1.3E-03	1.1E-01	1.1E-01	1.8E-03	2.6E-02	3.2E-08	3.2E-08
5D	2	998	1.5E+06	3.8E-01	9.1E-01	11200	3600	8.3E-03	2.0E-03	3.1E-05	2.0E-03	1.9E-03	2.9E-05	5.0E-04	5.3E-10	5.3E-10
5D	3	820	4.9E+02	1.2E-04	1.1E+00	11459	21641	2.3E-07	9.2E-08	8.5E-07	1.7E-07	8.5E-08	1.3E-13	4.5E-12	2.2E-07	5.7E-09
5D	4	821	4.1E+02	1.0E-04	1.1E+00	11459	21641	2.0E-07	7.9E-08	7.3E-07	1.5E-07	7.3E-08	1.1E-13	3.9E-12	1.9E-07	4.9E-09
5D	5	824	2.5E+02	6.0E-05	1.1E+00	11459	21641	1.2E-07	4.9E-08	4.6E-07	9.1E-08	4.5E-08	7.0E-14	2.4E-12	1.2E-07	3.0E-09
5D	6	997	1.3E+06	3.1E-01	9.5E-01	11459	3585.6	4.7E-03	1.2E-03	2.0E-05	1.1E-03	1.0E-03	1.5E-05	2.9E-04	2.8E-10	2.8E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5D	7	995	7.8E+06	2.0E+00	9.3E-01	13468	3604.4	4.5E-02	8.9E-03	1.2E-04	9.9E-03	1.0E-02	3.2E-04	2.3E-03	6.0E-09	6.1E-09
5D	8	998	5.9E+05	1.5E-01	9.6E-01	14800	3600	3.9E-03	2.1E-04	3.6E-06	2.6E-04	2.4E-04	1.3E-05	5.5E-05	2.4E-10	2.4E-10
5D	9	997	4.9E+05	1.2E-01	9.8E-01	15045	3655.1	3.0E-03	1.4E-04	2.5E-06	1.7E-04	1.6E-04	9.2E-06	3.6E-05	1.7E-10	1.7E-10
5D	10	995	9.8E+06	2.5E+00	8.8E-01	17073	3527.3	6.0E-02	5.7E-03	1.0E-04	8.7E-03	7.0E-03	4.2E-04	1.4E-03	7.6E-09	7.6E-09
5D	11	998	1.6E+04	4.1E-03	9.6E-01	18400	3600	1.0E-04	3.7E-06	7.8E-08	5.5E-06	5.0E-06	3.2E-07	9.4E-07	9.5E-12	5.8E-12
5D	12	995	6.3E+06	1.6E+00	1.0E+00	20600	3600.1	3.7E-02	6.3E-04	1.8E-04	1.1E-03	8.6E-04	5.5E-05	1.5E-04	4.1E-05	1.0E-06
5D	13	998	1.5E+04	3.6E-03	9.9E-01	22000	3600	8.5E-05	1.1E-06	4.5E-07	2.3E-06	1.5E-06	8.0E-08	2.3E-07	1.0E-07	2.8E-09
5D	14	995	8.1E+06	2.0E+00	9.9E-01	24200	3599.9	4.5E-02	3.5E-04	2.0E-04	1.1E-03	7.4E-04	1.9E-05	6.7E-05	4.2E-05	1.3E-06
5D	15	998	2.1E+03	5.3E-04	9.9E-01	25600	3600	1.2E-05	6.6E-08	3.4E-08	1.9E-07	1.4E-07	3.7E-09	1.3E-08	7.1E-09	2.2E-10
5D	16	995	4.3E+06	1.1E+00	1.0E+00	27800	3600.1	2.2E-02	7.5E-05	3.8E-05	1.8E-04	3.7E-04	2.8E-06	1.6E-05	5.1E-06	1.6E-07
5D	17	995	3.5E+06	8.7E-01	1.0E+00	31400	3599.9	1.8E-02	4.1E-05	1.7E-05	6.9E-05	2.9E-04	1.0E-06	9.5E-06	1.9E-06	5.9E-08
5D	18	995	2.8E+06	6.9E-01	1.0E+00	35000	3600.1	1.3E-02	2.2E-05	8.3E-06	2.7E-05	1.7E-04	4.1E-07	5.3E-06	7.5E-07	2.3E-08
5D	19	995	2.6E+06	6.5E-01	1.0E+00	38600	3599.9	1.2E-02	1.5E-05	5.6E-06	1.6E-05	1.2E-04	2.3E-07	3.6E-06	4.2E-07	1.3E-08
5D	20	995	2.5E+06	6.1E-01	1.0E+00	42200	3600	1.1E-02	9.0E-06	3.5E-06	9.8E-06	7.9E-05	1.3E-07	2.2E-06	2.4E-07	7.7E-09
5D	21	998	1.0E+04	2.6E-03	1.0E+00	43600	3600	4.6E-05	3.3E-08	1.3E-08	3.6E-08	2.9E-07	4.9E-10	8.0E-09	8.8E-10	2.8E-11
5D	22	995	2.6E+06	6.3E-01	1.0E+00	45800	3600.1	1.1E-02	5.8E-06	2.3E-06	6.6E-06	5.2E-05	8.7E-08	1.4E-06	1.6E-07	4.9E-09
5D	23	998	1.7E+04	4.3E-03	1.0E+00	47200	3599.8	7.5E-05	3.6E-08	1.4E-08	4.1E-08	3.2E-07	5.3E-10	8.7E-09	9.6E-10	3.0E-11
5D	24	995	2.5E+06	6.2E-01	1.0E+00	49400	3599.9	1.1E-02	3.8E-06	1.5E-06	4.4E-06	3.4E-05	5.5E-08	9.1E-07	1.0E-07	3.2E-09
5D	25	998	1.6E+04	4.0E-03	1.0E+00	50800	3600.1	6.8E-05	2.2E-08	8.8E-09	2.6E-08	2.0E-07	3.2E-10	5.3E-09	5.9E-10	1.9E-11
5D	26	995	3.6E+06	8.9E-01	1.0E+00	53000	3600	1.5E-02	3.6E-06	1.4E-06	5.2E-06	3.2E-05	5.2E-08	8.6E-07	9.4E-08	3.0E-09
5D	27	998	8.7E+04	2.1E-02	1.0E+00	54400	3600	3.6E-04	8.3E-08	3.3E-08	1.1E-07	7.4E-07	1.2E-09	2.0E-08	2.2E-09	6.9E-11
5D	28	997	5.3E+04	1.3E-02	1.0E+00	54700	3600.1	2.1E-04	4.6E-08	1.8E-08	6.0E-08	4.2E-07	6.8E-10	1.1E-08	1.2E-09	3.9E-11
5D	29	995	6.1E+05	1.5E-01	1.0E+00	56600	3599.9	2.3E-03	4.1E-07	1.6E-07	8.8E-07	3.5E-06	4.9E-09	9.7E-08	9.9E-09	3.2E-10
5D	30	998	1.8E+04	4.3E-03	1.0E+00	58000	3600.1	6.9E-05	1.2E-08	4.4E-09	2.7E-08	9.9E-08	1.5E-10	2.7E-09	2.8E-10	9.2E-12
5D	31	995	2.7E+06	6.5E-01	1.0E+00	60200	3600	1.0E-02	1.4E-06	5.2E-07	3.2E-06	1.1E-05	1.8E-08	3.1E-07	3.2E-08	1.1E-09
5D	32	998	2.5E+04	6.2E-03	1.0E+00	61600	3600.1	9.6E-05	1.2E-08	4.5E-09	3.0E-08	1.0E-07	1.6E-10	2.7E-09	2.8E-10	9.3E-12
5D	33	995	2.7E+06	6.5E-01	1.0E+00	63800	3600.2	9.8E-03	1.0E-06	3.7E-07	2.7E-06	8.3E-06	1.3E-08	2.3E-07	2.3E-08	7.7E-10
5D	34	995	2.1E+06	5.3E-01	1.0E+00	67400	3599.9	7.7E-03	6.3E-07	2.2E-07	1.9E-06	4.9E-06	7.7E-09	1.3E-07	1.4E-08	4.5E-10
5D	35	995	2.2E+06	5.4E-01	1.0E+00	71000	3599.9	7.7E-03	4.7E-07	1.6E-07	1.6E-06	3.5E-06	5.1E-09	9.5E-08	9.9E-09	3.3E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5D	36	995	3.1E+06	7.7E-01	1.0E+00	74600	3600.1	1.1E-02	5.5E-07	1.6E-07	2.4E-06	3.4E-06	5.4E-09	1.1E-07	9.2E-09	3.2E-10
5D	37	998	8.4E+04	2.1E-02	1.0E+00	76000	3599.9	2.9E-04	1.2E-08	4.0E-09	5.6E-08	8.8E-08	1.3E-10	2.5E-09	2.4E-10	8.2E-12
5D	38	997	7.6E+04	1.9E-02	1.0E+00	76300	2600	1.8E-04	7.2E-09	2.5E-09	3.0E-08	5.5E-08	8.5E-11	1.5E-09	1.6E-10	5.1E-12
5D	39	995	9.5E+05	2.3E-01	1.0E+00	78200	3600	3.1E-03	2.1E-07	3.8E-08	1.5E-06	7.7E-07	9.3E-10	3.5E-08	1.9E-09	7.8E-11
5D	40	995	2.5E+06	6.2E-01	1.0E+00	81800	3600	8.0E-03	5.3E-07	8.1E-08	3.5E-06	1.6E-06	2.1E-09	7.8E-08	3.8E-09	1.6E-10
5D	41	995	3.7E+06	9.2E-01	1.0E+00	85400	4000.1	1.3E-02	2.4E-06	2.4E-07	4.4E-06	2.4E-06	2.3E-09	6.0E-07	4.6E-09	2.3E-10
5D	42	995	3.9E+06	9.6E-01	1.0E+00	89400	2999.9	9.9E-03	4.7E-06	4.2E-07	2.8E-06	2.7E-06	1.4E-09	1.3E-06	2.9E-09	2.4E-10
5D	43	995	3.8E+06	9.5E-01	1.0E+00	92400	4000	1.3E-02	9.3E-06	8.7E-07	3.0E-06	5.0E-06	1.2E-09	2.6E-06	3.1E-09	3.9E-10
5D	44	995	3.8E+06	9.6E-01	1.0E+00	96400	3000	9.3E-03	8.2E-06	8.1E-07	1.7E-06	4.5E-06	9.3E-10	2.3E-06	1.8E-09	3.0E-10
5D	45	995	3.8E+06	9.7E-01	1.0E+00	99400	4000	1.2E-02	1.2E-05	1.3E-06	1.8E-06	6.8E-06	4.7E-10	3.2E-06	1.8E-09	3.9E-10
5D	46	995	3.8E+06	9.7E-01	1.0E+00	103400	3999.9	1.2E-02	1.2E-05	1.4E-06	1.4E-06	7.2E-06	4.7E-10	3.4E-06	1.3E-09	3.6E-10
5D	47	995	3.9E+06	9.8E-01	1.0E+00	107400	3000.1	8.7E-03	9.5E-06	1.2E-06	8.6E-07	5.7E-06	0.0E+00	2.6E-06	7.7E-10	2.6E-10
5D	48	995	3.9E+06	9.9E-01	1.0E+00	110400	4000	1.1E-02	1.3E-05	1.7E-06	1.0E-06	7.8E-06	2.3E-10	3.6E-06	8.2E-10	3.3E-10
5D	49	995	3.9E+06	9.9E-01	1.0E+00	114400	2999.9	8.2E-03	9.8E-06	1.4E-06	6.7E-07	6.0E-06	2.3E-10	2.7E-06	5.2E-10	2.4E-10
5D	50	995	3.9E+06	9.9E-01	1.0E+00	117400	4000.1	1.1E-02	1.1E-05	2.0E-06	8.2E-07	8.3E-06	0.0E+00	3.0E-06	6.2E-10	3.1E-10
5D	51	995	3.9E+06	9.9E-01	1.0E+00	121400	4000	1.0E-02	6.8E-06	2.0E-06	7.9E-07	9.0E-06	0.0E+00	1.9E-06	5.7E-10	3.1E-10
5D	52	995	3.9E+06	1.0E+00	1.0E+00	125400	2999.9	7.5E-03	3.5E-06	1.6E-06	5.4E-07	7.6E-06	0.0E+00	9.6E-07	4.2E-10	2.5E-10
5D	53	995	3.8E+06	1.0E+00	1.0E+00	128400	4000	9.7E-03	3.4E-06	2.5E-06	7.2E-07	1.2E-05	0.0E+00	9.3E-07	5.8E-10	3.5E-10
5D	54	995	3.8E+06	1.0E+00	1.0E+00	132400	3000	7.1E-03	1.9E-06	1.9E-06	5.2E-07	1.0E-05	2.3E-10	5.1E-07	4.7E-10	2.8E-10
5D	55	995	3.8E+06	1.0E+00	1.0E+00	135400	4000.1	9.1E-03	1.9E-06	2.3E-06	6.7E-07	1.6E-05	0.0E+00	5.3E-07	6.0E-10	3.9E-10
5D	56	995	3.8E+06	1.0E+00	1.0E+00	139400	3999.9	8.9E-03	1.5E-06	2.2E-06	6.4E-07	1.8E-05	0.0E+00	4.1E-07	6.3E-10	4.1E-10
5D	57	995	3.8E+06	1.0E+00	1.0E+00	143400	3000	6.4E-03	9.5E-07	1.6E-06	4.6E-07	1.5E-05	0.0E+00	2.5E-07	4.7E-10	3.2E-10
5D	58	995	3.8E+06	1.0E+00	1.0E+00	146400	4000	8.3E-03	1.1E-06	2.2E-06	6.1E-07	2.3E-05	0.0E+00	2.9E-07	6.3E-10	4.3E-10
5D	59	995	3.8E+06	1.0E+00	1.0E+00	150400	3000.1	6.0E-03	7.3E-07	1.6E-06	4.5E-07	2.0E-05	0.0E+00	2.0E-07	4.8E-10	3.3E-10
5D	60	995	3.8E+06	1.0E+00	1.0E+00	153400	3999.9	7.7E-03	9.1E-07	2.1E-06	5.5E-07	3.0E-05	0.0E+00	2.4E-07	6.3E-10	4.5E-10
5D	61	995	3.7E+06	9.8E-01	1.0E+00	157400	4000.1	7.3E-03	8.5E-07	2.1E-06	5.5E-07	3.5E-05	0.0E+00	2.3E-07	6.3E-10	4.5E-10
5D	62	995	3.6E+06	9.6E-01	1.0E+00	161400	2999.9	5.2E-03	6.0E-07	1.5E-06	3.7E-07	3.2E-05	0.0E+00	1.7E-07	4.4E-10	3.3E-10
5D	63	820	3.1E+01	1.7E-05	8.0E-01	162400	22400	4.4E-07	5.5E-11	2.9E-09	1.7E-10	1.1E-08	1.5E-13	2.0E-06	2.9E-12	3.0E-12
5D	64	995	3.6E+06	9.5E-01	1.0E+00	164400	4000.1	6.7E-03	7.7E-07	1.8E-06	5.2E-07	5.1E-05	0.0E+00	2.2E-07	5.8E-10	4.4E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
5D	65	995	3.8E+06	1.0E+00	1.0E+00	168400	3000	5.1E-03	6.0E-07	1.3E-06	3.7E-07	4.6E-05	0.0E+00	7.7E-05	4.4E-10	3.3E-10
5D	66	995	3.5E+06	9.4E-01	1.0E+00	171400	5400	8.3E-03	9.0E-07	1.9E-06	6.3E-07	7.9E-05	0.0E+00	7.4E-04	6.8E-10	5.4E-10
5D	67	995	3.1E+06	8.3E-01	1.0E+00	176800	4000	5.2E-03	4.9E-07	1.0E-06	3.9E-07	4.8E-05	0.0E+00	3.7E-04	3.9E-10	3.0E-10
5D	68	995	3.1E+06	8.1E-01	1.0E+00	180800	4000	4.9E-03	4.1E-07	8.8E-07	3.7E-07	4.6E-05	0.0E+00	2.5E-04	2.9E-10	2.4E-10
5D	69	995	3.5E+06	9.2E-01	1.0E+00	184800	3999.9	5.4E-03	4.2E-07	8.9E-07	4.2E-07	5.2E-05	0.0E+00	1.9E-04	2.9E-10	2.3E-10
5D	70	995	3.1E+06	8.3E-01	1.0E+00	188800	4000	4.7E-03	3.8E-07	7.7E-07	3.6E-07	4.7E-05	0.0E+00	1.2E-04	2.3E-10	2.0E-10
5D	71	995	3.1E+06	8.2E-01	1.0E+00	192800	4000.2	4.5E-03	3.5E-07	7.2E-07	3.3E-07	4.5E-05	0.0E+00	8.5E-05	2.2E-10	1.7E-10
5D	72	995	3.2E+06	8.5E-01	1.0E+00	196800	3999.9	4.6E-03	3.6E-07	7.0E-07	3.6E-07	3.9E-05	0.0E+00	6.4E-05	1.8E-10	1.5E-10
5D	73	995	3.2E+06	8.5E-01	1.0E+00	200800	4000	4.4E-03	3.3E-07	6.6E-07	3.6E-07	3.0E-05	0.0E+00	4.6E-05	1.7E-10	1.4E-10
5D	74	995	3.1E+06	8.2E-01	1.0E+00	204800	3999.9	4.1E-03	3.4E-07	6.1E-07	3.1E-07	2.2E-05	0.0E+00	3.2E-05	1.7E-10	1.3E-10
5D	75	995	3.3E+06	8.6E-01	1.0E+00	208800	4000.2	4.2E-03	3.9E-07	6.3E-07	3.3E-07	1.7E-05	0.0E+00	2.5E-05	1.5E-10	1.3E-10
5D	76	995	3.1E+06	8.1E-01	1.0E+00	212800	3999.8	3.8E-03	3.9E-07	6.1E-07	3.0E-07	1.2E-05	0.0E+00	1.7E-05	1.5E-10	1.2E-10
5D	77	995	3.1E+06	8.2E-01	1.0E+00	216800	4000	3.7E-03	3.7E-07	6.2E-07	3.0E-07	8.7E-06	0.0E+00	1.3E-05	1.4E-10	1.1E-10
5D	78	995	3.1E+06	8.2E-01	1.0E+00	220800	4000	3.7E-03	3.8E-07	6.3E-07	2.8E-07	6.3E-06	0.0E+00	9.5E-06	1.2E-10	9.9E-11
5D	79	995	3.5E+06	9.1E-01	1.0E+00	224800	4000.1	3.9E-03	4.4E-07	7.2E-07	3.1E-07	5.1E-06	0.0E+00	7.9E-06	1.4E-10	1.1E-10
5D	80	995	3.4E+06	8.8E-01	1.0E+00	228800	4000	3.7E-03	5.7E-07	7.3E-07	2.8E-07	3.5E-06	0.0E+00	6.3E-06	1.7E-10	1.4E-10
5D	81	995	3.2E+06	8.3E-01	9.9E-01	232800	4000	3.3E-03	5.7E-07	7.0E-07	2.8E-07	2.4E-06	0.0E+00	4.7E-06	1.6E-10	1.4E-10
5D	82	995	3.3E+06	8.6E-01	9.9E-01	236800	4000	3.3E-03	5.5E-07	6.6E-07	2.5E-07	1.8E-06	0.0E+00	3.8E-06	1.6E-10	1.4E-10
5D	83	995	3.2E+06	8.4E-01	9.9E-01	240800	4000	3.2E-03	5.5E-07	5.8E-07	2.7E-07	1.2E-06	0.0E+00	2.9E-06	1.5E-10	1.3E-10
5D	84	995	3.5E+06	9.1E-01	9.9E-01	244800	3999.9	3.3E-03	6.6E-07	5.8E-07	2.5E-07	9.2E-07	0.0E+00	2.5E-06	1.6E-10	1.4E-10
5D	85	995	3.2E+06	8.3E-01	9.9E-01	248800	4000.1	2.9E-03	6.6E-07	5.3E-07	2.5E-07	6.1E-07	0.0E+00	2.1E-06	1.5E-10	1.4E-10
5D	86	995	3.3E+06	8.5E-01	9.9E-01	252800	6400	4.6E-03	1.1E-06	8.4E-07	3.9E-07	6.6E-07	0.0E+00	2.8E-06	2.5E-10	2.2E-10
6	1	820	1.6E+03	4.3E-04	8.8E-01	53500	21600	9.0E-05	9.5E-06	3.5E-07	1.2E-05	1.2E-05	2.4E-07	2.3E-06	2.7E-08	5.5E-10
6	2	821	1.3E+03	3.6E-04	8.8E-01	53500	21600	7.4E-05	7.9E-06	3.0E-07	1.0E-05	9.8E-06	2.0E-07	1.9E-06	2.2E-08	4.6E-10
6	3	824	7.6E+02	2.0E-04	8.8E-01	53500	21600	4.5E-05	4.9E-06	1.8E-07	6.3E-06	6.0E-06	1.2E-07	1.2E-06	1.3E-08	2.7E-10
6	4	27	3.6E+06	8.6E-01	1.2E+00	75100	3599.9	4.3E-07	1.2E-11	1.3E-12	2.3E-11	1.8E-11	4.2E-13	2.7E-12	1.0E-13	2.2E-15
6	5	820	1.1E+03	3.3E-04	9.2E-01	75100	21573	1.0E-04	1.2E-06	3.5E-07	2.5E-06	2.0E-06	3.2E-08	1.8E-07	1.8E-08	4.6E-10
6	6	821	8.8E+02	2.7E-04	9.2E-01	75100	21573	8.2E-05	9.5E-07	2.9E-07	2.1E-06	1.7E-06	2.6E-08	1.5E-07	1.5E-08	3.8E-10
6	7	824	5.0E+02	1.6E-04	9.2E-01	75100	21573	4.8E-05	5.6E-07	1.7E-07	1.2E-06	9.9E-07	1.6E-08	9.0E-08	9.0E-09	2.2E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	8	27	3.6E+06	8.6E-01	1.2E+00	78700	3600	5.0E-07	8.1E-12	1.1E-12	1.7E-11	1.2E-11	2.7E-13	1.7E-12	8.0E-14	1.7E-15
6	9	27	3.6E+06	8.6E-01	1.2E+00	82300	3600	5.8E-07	4.9E-12	8.4E-13	1.3E-11	7.5E-12	1.6E-13	9.9E-13	5.1E-14	1.1E-15
6	10	27	3.6E+06	8.6E-01	1.2E+00	85900	3595.4	6.4E-07	3.2E-12	5.9E-13	1.0E-11	4.9E-12	1.0E-13	6.4E-13	3.4E-14	7.8E-16
6	11	27	3.6E+06	8.5E-01	1.2E+00	89495	3904.7	7.6E-07	2.6E-12	4.9E-13	9.9E-12	4.0E-12	7.4E-14	5.1E-13	2.6E-14	6.6E-16
6	12	27	3.6E+06	8.6E-01	1.2E+00	93400	3273.2	7.0E-07	1.8E-12	3.4E-13	7.8E-12	2.8E-12	4.4E-14	3.6E-13	1.7E-14	4.7E-16
6	13	27	3.6E+06	8.5E-01	1.2E+00	96673	3616.2	8.3E-07	1.9E-12	3.1E-13	8.3E-12	2.7E-12	3.5E-14	3.7E-13	1.4E-14	4.6E-16
6	14	820	7.4E+02	2.9E-04	9.2E-01	96673	21727	9.2E-05	1.7E-06	8.1E-08	1.8E-06	1.3E-06	5.0E-09	4.0E-07	2.9E-09	2.1E-10
6	15	821	6.1E+02	2.4E-04	9.2E-01	96673	21727	7.6E-05	1.4E-06	6.6E-08	1.4E-06	1.0E-06	4.1E-09	3.3E-07	2.4E-09	1.8E-10
6	16	824	3.5E+02	1.4E-04	9.3E-01	96673	21727	4.4E-05	8.2E-07	3.9E-08	8.5E-07	6.1E-07	2.4E-09	1.9E-07	1.4E-09	1.0E-10
6	17	27	3.6E+06	8.5E-01	1.2E+00	100290	3625.1	8.8E-07	2.0E-12	2.7E-13	8.2E-12	2.6E-12	2.7E-14	4.1E-13	1.2E-14	4.5E-16
6	18	27	3.6E+06	8.5E-01	1.2E+00	103910	3594.9	9.3E-07	2.4E-12	2.4E-13	8.4E-12	2.6E-12	2.2E-14	5.1E-13	1.0E-14	4.6E-16
6	19	27	3.6E+06	8.5E-01	1.2E+00	107510	3601.9	9.9E-07	2.9E-12	2.2E-13	8.6E-12	2.8E-12	1.9E-14	6.4E-13	9.1E-15	4.8E-16
6	20	27	3.6E+06	8.5E-01	1.2E+00	111110	3610.4	1.0E-06	3.5E-12	2.1E-13	8.9E-12	2.9E-12	1.6E-14	8.1E-13	8.3E-15	5.0E-16
6	21	27	3.6E+06	8.5E-01	1.2E+00	114720	3678.4	1.1E-06	4.4E-12	2.1E-13	9.6E-12	3.2E-12	1.5E-14	1.0E-12	7.9E-15	5.4E-16
6	22	27	3.6E+06	8.5E-01	1.2E+00	118400	3492.9	1.1E-06	4.9E-12	1.9E-13	9.4E-12	3.2E-12	1.3E-14	1.2E-12	7.2E-15	5.3E-16
6	23	820	4.5E+02	2.4E-04	9.3E-01	118400	21000	7.8E-05	2.2E-06	6.1E-08	1.7E-06	1.4E-06	3.4E-09	5.4E-07	2.0E-09	2.1E-10
6	24	821	3.7E+02	2.0E-04	9.3E-01	118400	21000	6.4E-05	1.8E-06	5.0E-08	1.4E-06	1.1E-06	2.8E-09	4.5E-07	1.6E-09	1.7E-10
6	25	824	2.1E+02	1.2E-04	9.4E-01	118400	21000	3.9E-05	1.1E-06	3.0E-08	8.6E-07	6.7E-07	1.7E-09	2.7E-07	9.6E-10	1.0E-10
6	26	27	3.6E+06	8.5E-01	1.2E+00	121890	3607.1	1.2E-06	5.6E-12	1.9E-13	9.8E-12	3.5E-12	1.3E-14	1.3E-12	7.0E-15	5.7E-16
6	27	27	3.6E+06	8.5E-01	1.2E+00	125500	3335.4	1.1E-06	5.5E-12	1.7E-13	9.1E-12	3.3E-12	1.1E-14	1.3E-12	6.2E-15	5.4E-16
6	28	27	3.6E+06	8.5E-01	1.2E+00	128840	3564.6	1.2E-06	6.1E-12	1.8E-13	9.8E-12	3.7E-12	1.2E-14	1.5E-12	6.4E-15	5.9E-16
6	29	27	3.6E+06	8.5E-01	1.2E+00	132400	4000.1	1.4E-06	6.8E-12	2.0E-13	1.1E-11	4.2E-12	1.2E-14	1.6E-12	6.7E-15	6.5E-16
6	30	27	3.6E+06	8.5E-01	1.2E+00	136400	2999.9	1.1E-06	5.1E-12	1.5E-13	8.0E-12	3.2E-12	8.6E-15	1.2E-12	4.8E-15	4.9E-16
6	31	27	3.6E+06	8.5E-01	1.2E+00	139400	4000	1.5E-06	6.8E-12	2.0E-13	1.1E-11	4.4E-12	1.1E-14	1.7E-12	6.1E-15	6.6E-16
6	32	820	4.2E+02	2.6E-04	9.2E-01	139400	22000	8.7E-05	2.1E-06	7.3E-08	2.0E-06	1.7E-06	2.6E-09	5.0E-07	1.5E-09	2.2E-10
6	33	821	3.5E+02	2.1E-04	9.2E-01	139400	22000	7.1E-05	1.7E-06	6.0E-08	1.6E-06	1.4E-06	2.1E-09	4.1E-07	1.3E-09	1.8E-10
6	34	824	2.0E+02	1.2E-04	9.2E-01	139400	22000	4.2E-05	1.0E-06	3.5E-08	9.7E-07	8.4E-07	1.3E-09	2.5E-07	7.5E-10	1.0E-10
6	35	27	3.6E+06	8.5E-01	1.2E+00	143400	3999.9	1.6E-06	6.8E-12	2.1E-13	1.1E-11	4.7E-12	1.0E-14	1.7E-12	5.9E-15	6.7E-16
6	36	27	3.6E+06	8.5E-01	1.2E+00	147400	3000	1.2E-06	5.1E-12	1.6E-13	8.4E-12	3.7E-12	7.5E-15	1.2E-12	4.2E-15	5.1E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	37	27	3.6E+06	8.5E-01	1.2E+00	150400	4000	1.6E-06	6.8E-12	2.2E-13	1.1E-11	5.1E-12	9.5E-15	1.6E-12	5.4E-15	6.8E-16
6	38	27	3.6E+06	8.5E-01	1.2E+00	154400	3000.2	1.3E-06	5.0E-12	1.7E-13	8.7E-12	3.9E-12	6.8E-15	1.2E-12	3.9E-15	5.0E-16
6	39	27	3.6E+06	8.5E-01	1.2E+00	157400	3999.9	1.7E-06	6.5E-12	2.2E-13	1.2E-11	5.3E-12	8.5E-15	1.6E-12	4.9E-15	6.7E-16
6	40	27	3.6E+06	8.5E-01	1.2E+00	161400	3999.9	1.8E-06	6.3E-12	2.2E-13	1.2E-11	5.4E-12	8.0E-15	1.5E-12	4.6E-15	6.6E-16
6	41	820	5.1E+02	3.0E-04	8.7E-01	161400	23400	1.1E-04	1.8E-06	6.8E-08	1.7E-06	2.1E-06	2.0E-09	4.3E-07	1.2E-09	2.2E-10
6	42	821	4.2E+02	2.5E-04	8.7E-01	161400	23400	8.9E-05	1.5E-06	5.6E-08	1.4E-06	1.7E-06	1.6E-09	3.5E-07	9.9E-10	1.8E-10
6	43	824	2.4E+02	1.4E-04	8.7E-01	161400	23400	5.2E-05	8.6E-07	3.3E-08	8.3E-07	9.9E-07	9.4E-10	2.0E-07	5.8E-10	1.0E-10
6	44	27	3.6E+06	8.5E-01	1.2E+00	165400	3000.1	1.4E-06	4.6E-12	1.6E-13	8.6E-12	4.1E-12	5.7E-15	1.1E-12	3.3E-15	4.9E-16
6	45	27	3.6E+06	8.5E-01	1.2E+00	168400	3999.9	1.9E-06	5.9E-12	2.1E-13	1.1E-11	5.5E-12	7.1E-15	1.4E-12	4.2E-15	6.4E-16
6	46	27	3.6E+06	8.5E-01	1.2E+00	172400	4400.1	2.1E-06	6.2E-12	2.2E-13	1.2E-11	6.2E-12	7.3E-15	1.5E-12	4.3E-15	6.9E-16
6	47	27	3.6E+06	8.5E-01	1.2E+00	176800	4000.1	2.0E-06	5.3E-12	2.0E-13	1.1E-11	5.7E-12	6.2E-15	1.3E-12	3.7E-15	6.2E-16
6	48	27	3.6E+06	8.5E-01	1.2E+00	180800	3999.8	2.0E-06	5.1E-12	1.9E-13	1.1E-11	5.8E-12	5.8E-15	1.2E-12	3.5E-15	6.1E-16
6	49	27	3.6E+06	8.5E-01	1.2E+00	184800	4000.1	2.1E-06	4.8E-12	1.9E-13	1.1E-11	5.9E-12	5.5E-15	1.1E-12	3.3E-15	6.0E-16
6	50	820	5.8E+02	3.4E-04	8.4E-01	184800	20000	1.0E-04	1.2E-06	5.0E-08	1.2E-06	2.0E-06	1.2E-09	2.7E-07	8.0E-10	1.8E-10
6	51	821	4.8E+02	2.8E-04	8.3E-01	184800	20000	8.5E-05	9.6E-07	4.2E-08	9.6E-07	1.7E-06	1.0E-09	2.2E-07	6.6E-10	1.5E-10
6	52	824	2.7E+02	1.6E-04	8.4E-01	184800	20000	5.0E-05	5.6E-07	2.4E-08	5.6E-07	9.7E-07	6.0E-10	1.3E-07	3.9E-10	8.5E-11
6	53	27	3.6E+06	8.5E-01	1.2E+00	188800	3999.9	2.1E-06	4.5E-12	1.8E-13	1.1E-11	6.0E-12	5.1E-15	1.1E-12	3.1E-15	5.9E-16
6	54	27	3.6E+06	8.5E-01	1.2E+00	192800	4000.1	2.2E-06	4.2E-12	1.7E-13	1.0E-11	6.1E-12	4.8E-15	1.0E-12	2.9E-15	5.8E-16
6	55	27	3.6E+06	8.6E-01	1.2E+00	196800	3999.9	2.2E-06	4.0E-12	1.7E-13	1.0E-11	6.2E-12	4.5E-15	9.4E-13	2.8E-15	5.7E-16
6	56	27	3.6E+06	8.6E-01	1.2E+00	200800	4000.1	2.3E-06	3.9E-12	1.7E-13	1.0E-11	6.4E-12	4.4E-15	9.1E-13	2.7E-15	5.8E-16
6	57	27	3.6E+06	8.6E-01	1.2E+00	204800	3999.9	2.3E-06	3.8E-12	1.6E-13	1.0E-11	6.6E-12	4.2E-15	8.8E-13	2.7E-15	5.8E-16
6	58	820	6.5E+02	3.7E-04	8.0E-01	204800	20000	1.1E-04	9.0E-07	4.3E-08	9.4E-07	2.0E-06	9.7E-10	2.1E-07	6.5E-10	1.7E-10
6	59	821	5.3E+02	3.1E-04	8.1E-01	204800	20000	9.3E-05	7.5E-07	3.6E-08	7.8E-07	1.7E-06	8.1E-10	1.7E-07	5.4E-10	1.4E-10
6	60	824	3.0E+02	1.7E-04	8.1E-01	204800	20000	5.5E-05	4.4E-07	2.1E-08	4.6E-07	9.8E-07	4.7E-10	1.0E-07	3.2E-10	8.2E-11
6	61	27	3.6E+06	8.6E-01	1.2E+00	208800	4000.1	2.4E-06	3.7E-12	1.6E-13	1.0E-11	6.7E-12	4.1E-15	8.5E-13	2.6E-15	5.9E-16
6	62	27	3.6E+06	8.6E-01	1.2E+00	212800	4000.1	2.5E-06	3.5E-12	1.6E-13	1.0E-11	6.8E-12	4.0E-15	8.2E-13	2.5E-15	5.9E-16
6	63	27	3.6E+06	8.6E-01	1.2E+00	216800	3999.9	2.5E-06	3.4E-12	1.6E-13	1.0E-11	6.9E-12	3.8E-15	7.8E-13	2.4E-15	5.9E-16
6	64	27	3.6E+06	8.6E-01	1.2E+00	220800	4000	2.6E-06	3.3E-12	1.5E-13	1.0E-11	6.9E-12	3.7E-15	7.5E-13	2.3E-15	5.9E-16
6	65	27	3.6E+06	8.6E-01	1.2E+00	224800	4000	2.6E-06	3.1E-12	1.5E-13	1.0E-11	7.0E-12	3.5E-15	7.1E-13	2.2E-15	5.8E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	66	820	7.1E+02	4.0E-04	7.8E-01	224800	24000	1.4E-04	7.9E-07	4.4E-08	8.6E-07	2.8E-06	9.5E-10	1.2E-05	6.1E-10	1.9E-10
6	67	821	5.9E+02	3.3E-04	7.8E-01	224800	24000	1.2E-04	6.6E-07	3.6E-08	7.2E-07	2.3E-06	7.9E-10	1.0E-05	5.0E-10	1.6E-10
6	68	824	3.3E+02	1.9E-04	7.8E-01	224800	24000	7.0E-05	3.8E-07	2.1E-08	4.2E-07	1.4E-06	4.6E-10	5.9E-06	3.0E-10	9.4E-11
6	69	27	3.6E+06	8.6E-01	1.2E+00	228800	3999.9	2.7E-06	2.9E-12	1.4E-13	1.0E-11	6.9E-12	3.3E-15	6.6E-13	2.1E-15	5.6E-16
6	70	27	3.6E+06	8.6E-01	1.2E+00	232800	4000.1	2.7E-06	2.6E-12	1.3E-13	9.8E-12	6.6E-12	3.0E-15	5.9E-13	1.9E-15	5.3E-16
6	71	27	3.6E+06	8.6E-01	1.2E+00	236800	3999.9	2.8E-06	2.3E-12	1.2E-13	9.7E-12	6.5E-12	2.8E-15	5.3E-13	1.7E-15	5.0E-16
6	72	27	3.6E+06	8.6E-01	1.2E+00	240800	4000.1	2.8E-06	2.1E-12	1.1E-13	9.5E-12	6.5E-12	2.6E-15	4.8E-13	1.6E-15	4.8E-16
6	73	27	3.6E+06	8.6E-01	1.2E+00	244800	4000.1	2.9E-06	1.9E-12	1.1E-13	9.4E-12	6.7E-12	2.5E-15	2.3E-11	1.5E-15	4.6E-16
6	74	27	3.6E+06	8.6E-01	1.2E+00	248800	3999.9	2.9E-06	1.7E-12	1.0E-13	9.2E-12	6.8E-12	2.4E-15	8.9E-11	1.4E-15	4.5E-16
6	75	820	7.6E+02	4.2E-04	7.7E-01	248800	20000	1.3E-04	4.4E-07	3.7E-08	5.0E-07	2.3E-06	6.3E-10	7.0E-05	3.9E-10	1.6E-10
6	76	821	6.3E+02	3.5E-04	7.7E-01	248800	20000	1.0E-04	3.6E-07	3.0E-08	4.1E-07	1.9E-06	5.1E-10	5.7E-05	3.2E-10	1.3E-10
6	77	824	3.6E+02	2.0E-04	7.7E-01	248800	20000	6.1E-05	2.1E-07	1.8E-08	2.4E-07	1.1E-06	3.0E-10	3.4E-05	1.9E-10	7.9E-11
6	78	27	3.6E+06	8.6E-01	1.2E+00	252800	4000.1	3.0E-06	1.6E-12	9.8E-14	9.1E-12	6.7E-12	2.2E-15	1.3E-10	1.3E-15	4.4E-16
6	79	27	3.6E+06	8.6E-01	1.2E+00	256800	4000	3.0E-06	1.4E-12	9.8E-14	9.0E-12	6.5E-12	2.1E-15	1.5E-10	1.2E-15	4.3E-16
6	80	27	3.6E+06	8.6E-01	1.2E+00	260800	4000	3.0E-06	1.3E-12	9.9E-14	8.9E-12	6.3E-12	2.0E-15	1.6E-10	1.1E-15	4.4E-16
6	81	27	3.6E+06	8.6E-01	1.2E+00	264800	3999.9	3.1E-06	1.2E-12	1.0E-13	8.9E-12	6.0E-12	1.9E-15	1.6E-10	1.1E-15	4.4E-16
6	82	27	3.6E+06	8.6E-01	1.2E+00	268800	3999.9	3.1E-06	1.2E-12	1.0E-13	8.8E-12	5.8E-12	1.8E-15	1.6E-10	1.1E-15	4.5E-16
6	83	820	7.9E+02	4.4E-04	7.6E-01	268800	24000	1.6E-04	4.0E-07	5.1E-08	4.8E-07	2.3E-06	6.0E-10	6.3E-05	4.3E-10	2.2E-10
6	84	821	6.5E+02	3.6E-04	7.6E-01	268800	24000	1.3E-04	3.3E-07	4.2E-08	4.0E-07	1.9E-06	4.9E-10	5.2E-05	3.5E-10	1.8E-10
6	85	824	3.7E+02	2.0E-04	7.6E-01	268800	24000	7.5E-05	1.9E-07	2.5E-08	2.3E-07	1.1E-06	2.9E-10	3.0E-05	2.1E-10	1.1E-10
6	86	27	3.6E+06	8.6E-01	1.2E+00	272800	4000.1	3.2E-06	1.1E-12	1.0E-13	8.8E-12	5.7E-12	1.7E-15	1.6E-10	1.0E-15	4.6E-16
6	87	27	3.6E+06	8.6E-01	1.2E+00	276800	3999.9	3.2E-06	1.0E-12	1.1E-13	8.8E-12	5.5E-12	1.7E-15	1.5E-10	1.0E-15	4.7E-16
6	88	27	3.6E+06	8.6E-01	1.2E+00	280800	4000.1	3.3E-06	9.9E-13	1.1E-13	8.7E-12	5.4E-12	1.6E-15	1.5E-10	1.0E-15	4.8E-16
6	89	27	3.6E+06	8.6E-01	1.2E+00	284800	4000.1	3.3E-06	9.4E-13	1.1E-13	8.7E-12	5.2E-12	1.6E-15	1.4E-10	9.8E-16	4.9E-16
6	90	27	3.6E+06	8.6E-01	1.2E+00	288800	3999.9	3.3E-06	9.0E-13	1.1E-13	8.7E-12	5.1E-12	1.5E-15	1.4E-10	9.7E-16	5.0E-16
6	91	27	3.6E+06	8.6E-01	1.2E+00	292800	4000	3.4E-06	8.6E-13	1.2E-13	8.6E-12	4.9E-12	1.4E-15	1.3E-10	9.5E-16	5.1E-16
6	92	820	8.2E+02	4.4E-04	7.6E-01	292800	20000	1.3E-04	2.6E-07	4.9E-08	3.3E-07	1.6E-06	4.0E-10	4.0E-05	3.4E-10	2.1E-10
6	93	821	6.7E+02	3.7E-04	7.6E-01	292800	20000	1.1E-04	2.2E-07	4.0E-08	2.7E-07	1.3E-06	3.3E-10	3.3E-05	2.8E-10	1.7E-10
6	94	824	3.8E+02	2.1E-04	7.6E-01	292800	20000	6.3E-05	1.3E-07	2.4E-08	1.6E-07	7.9E-07	1.9E-10	1.9E-05	1.6E-10	1.0E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	95	27	3.6E+06	8.6E-01	1.2E+00	296800	4000.1	3.4E-06	8.1E-13	1.2E-13	8.6E-12	4.7E-12	1.4E-15	1.2E-10	9.4E-16	5.2E-16
6	96	27	3.6E+06	8.6E-01	1.2E+00	300800	3999.9	3.4E-06	7.8E-13	1.2E-13	8.6E-12	4.6E-12	1.3E-15	1.2E-10	9.3E-16	5.3E-16
6	97	27	3.6E+06	8.6E-01	1.2E+00	304800	4000.1	3.5E-06	7.4E-13	1.2E-13	8.6E-12	4.5E-12	1.3E-15	1.1E-10	9.2E-16	5.4E-16
6	98	27	3.6E+06	8.6E-01	1.2E+00	308800	3999.9	3.5E-06	7.0E-13	1.3E-13	8.5E-12	4.3E-12	1.2E-15	1.1E-10	9.1E-16	5.4E-16
6	99	27	3.6E+06	8.6E-01	1.2E+00	312800	4000	3.5E-06	6.7E-13	1.3E-13	8.5E-12	4.2E-12	1.2E-15	1.0E-10	8.9E-16	5.5E-16
6	100	820	8.4E+02	4.5E-04	7.6E-01	312800	20000	1.3E-04	2.1E-07	5.2E-08	2.7E-07	1.4E-06	3.2E-10	3.2E-05	3.2E-10	2.2E-10
6	101	821	6.9E+02	3.7E-04	7.6E-01	312800	20000	1.1E-04	1.7E-07	4.2E-08	2.2E-07	1.2E-06	2.6E-10	2.6E-05	2.6E-10	1.8E-10
6	102	824	3.9E+02	2.1E-04	7.6E-01	312800	20000	6.3E-05	1.0E-07	2.5E-08	1.3E-07	6.8E-07	1.5E-10	1.5E-05	1.5E-10	1.1E-10
6	103	27	3.6E+06	8.6E-01	1.2E+00	316800	4000	3.6E-06	6.4E-13	1.3E-13	8.5E-12	4.0E-12	1.1E-15	9.6E-11	8.8E-16	5.6E-16
6	104	27	3.6E+06	8.6E-01	1.2E+00	320800	3999.9	3.6E-06	6.1E-13	1.3E-13	8.4E-12	3.9E-12	1.1E-15	9.1E-11	8.7E-16	5.6E-16
6	105	27	3.6E+06	8.6E-01	1.2E+00	324800	4000.1	3.6E-06	5.8E-13	1.3E-13	8.4E-12	3.8E-12	1.0E-15	8.7E-11	8.6E-16	5.6E-16
6	106	27	3.6E+06	8.6E-01	1.2E+00	328800	4000	3.7E-06	5.5E-13	1.3E-13	8.4E-12	3.7E-12	1.0E-15	8.2E-11	8.5E-16	5.6E-16
6	107	27	3.6E+06	8.6E-01	1.2E+00	332800	3999.9	3.7E-06	5.3E-13	1.3E-13	8.4E-12	3.6E-12	9.6E-16	7.8E-11	8.3E-16	5.7E-16
6	108	820	8.6E+02	4.6E-04	7.6E-01	332800	24000	1.6E-04	1.9E-07	6.3E-08	2.6E-07	1.4E-06	3.0E-10	2.9E-05	3.6E-10	2.7E-10
6	109	821	7.1E+02	3.8E-04	7.6E-01	332800	24000	1.3E-04	1.6E-07	5.1E-08	2.1E-07	1.2E-06	2.4E-10	2.3E-05	2.9E-10	2.2E-10
6	110	824	4.0E+02	2.1E-04	7.6E-01	332800	24000	7.7E-05	9.3E-08	3.0E-08	1.3E-07	6.9E-07	1.4E-10	1.4E-05	1.7E-10	1.3E-10
6	111	27	3.6E+06	8.6E-01	1.2E+00	336800	4000.1	3.7E-06	5.0E-13	1.3E-13	8.3E-12	3.5E-12	9.2E-16	7.4E-11	8.2E-16	5.7E-16
6	112	27	3.6E+06	8.6E-01	1.2E+00	340800	4000.1	3.7E-06	4.8E-13	1.3E-13	8.3E-12	3.4E-12	8.8E-16	7.0E-11	8.1E-16	5.7E-16
6	113	27	3.6E+06	8.6E-01	1.2E+00	344800	3999.9	3.8E-06	4.5E-13	1.3E-13	8.3E-12	3.2E-12	8.5E-16	6.7E-11	8.0E-16	5.7E-16
6	114	27	3.6E+06	8.6E-01	1.2E+00	348800	3999.9	3.8E-06	4.3E-13	1.3E-13	8.3E-12	3.1E-12	8.1E-16	6.3E-11	7.8E-16	5.6E-16
6	115	27	3.6E+06	8.6E-01	1.2E+00	352800	4000.1	3.8E-06	4.1E-13	1.3E-13	8.3E-12	3.0E-12	7.8E-16	6.0E-11	7.7E-16	5.6E-16
6	116	27	3.6E+06	8.6E-01	1.2E+00	356800	3200.1	3.1E-06	3.1E-13	1.1E-13	6.6E-12	2.4E-12	6.0E-16	4.5E-11	6.0E-16	4.5E-16
6	117	820	8.8E+02	4.6E-04	7.5E-01	356800	20000	1.4E-04	1.2E-07	5.1E-08	1.7E-07	1.0E-06	1.9E-10	1.7E-05	2.7E-10	2.1E-10
6	118	821	7.3E+02	3.8E-04	7.5E-01	356800	20000	1.1E-04	9.9E-08	4.2E-08	1.4E-07	8.1E-07	1.5E-10	1.4E-05	2.2E-10	1.7E-10
6	119	824	4.1E+02	2.2E-04	7.5E-01	356800	20000	6.5E-05	5.8E-08	2.4E-08	8.3E-08	4.8E-07	9.0E-11	8.3E-06	1.3E-10	1.0E-10
6	120	27	3.6E+06	8.6E-01	1.2E+00	360000	4799.8	4.7E-06	4.5E-13	1.6E-13	9.9E-12	3.4E-12	8.7E-16	6.4E-11	8.9E-16	6.7E-16
6	121	27	3.6E+06	8.6E-01	1.2E+00	364800	4000	3.9E-06	3.5E-13	1.3E-13	8.2E-12	2.7E-12	6.9E-16	5.0E-11	7.3E-16	5.5E-16
6	122	27	3.6E+06	8.6E-01	1.2E+00	368800	4000	3.9E-06	3.3E-13	1.3E-13	8.2E-12	2.6E-12	6.6E-16	4.7E-11	7.1E-16	5.4E-16
6	123	27	3.6E+06	8.6E-01	1.2E+00	372800	4000.2	4.0E-06	3.2E-13	1.3E-13	8.2E-12	2.5E-12	6.3E-16	4.5E-11	7.0E-16	5.4E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	124	27	3.6E+06	8.6E-01	1.2E+00	376800	3999.9	4.0E-06	3.0E-13	1.3E-13	8.2E-12	2.4E-12	6.1E-16	4.2E-11	6.8E-16	5.3E-16
6	125	820	9.0E+02	4.7E-04	7.5E-01	376800	24000	1.6E-04	1.1E-07	5.7E-08	1.6E-07	9.7E-07	1.7E-10	1.5E-05	2.9E-10	2.4E-10
6	126	821	7.4E+02	3.9E-04	7.5E-01	376800	24000	1.3E-04	8.7E-08	4.7E-08	1.3E-07	7.9E-07	1.4E-10	1.2E-05	2.3E-10	2.0E-10
6	127	824	4.2E+02	2.2E-04	7.5E-01	376800	24000	7.9E-05	5.1E-08	2.7E-08	7.8E-08	4.7E-07	8.0E-11	7.2E-06	1.4E-10	1.1E-10
6	128	27	3.6E+06	8.6E-01	1.2E+00	380800	4000	4.0E-06	2.8E-13	1.3E-13	8.2E-12	2.4E-12	5.8E-16	4.0E-11	6.7E-16	5.3E-16
6	129	27	3.6E+06	8.6E-01	1.2E+00	384800	4000	4.0E-06	2.7E-13	1.2E-13	8.2E-12	2.3E-12	5.6E-16	3.7E-11	6.5E-16	5.2E-16
6	130	27	3.6E+06	8.6E-01	1.2E+00	388800	4000.1	4.0E-06	2.5E-13	1.2E-13	8.2E-12	2.2E-12	5.4E-16	3.5E-11	6.4E-16	5.1E-16
6	131	27	3.6E+06	8.6E-01	1.2E+00	392800	4000	4.1E-06	2.4E-13	1.2E-13	8.2E-12	2.1E-12	5.2E-16	3.3E-11	6.2E-16	5.0E-16
6	132	27	3.6E+06	8.6E-01	1.2E+00	396800	3999.8	4.1E-06	2.3E-13	1.2E-13	8.1E-12	2.0E-12	4.9E-16	3.1E-11	6.1E-16	5.0E-16
6	133	27	3.6E+06	8.6E-01	1.2E+00	400800	4000.2	4.1E-06	2.1E-13	1.2E-13	8.1E-12	1.9E-12	4.7E-16	2.9E-11	5.9E-16	4.9E-16
6	134	820	9.2E+02	4.8E-04	7.5E-01	400800	20000	1.4E-04	6.4E-08	4.4E-08	1.1E-07	6.4E-07	1.0E-10	8.7E-06	2.1E-10	1.8E-10
6	135	821	7.6E+02	3.9E-04	7.5E-01	400800	20000	1.1E-04	5.2E-08	3.6E-08	8.6E-08	5.2E-07	8.3E-11	7.1E-06	1.7E-10	1.5E-10
6	136	824	4.3E+02	2.2E-04	7.5E-01	400800	20000	6.6E-05	3.0E-08	2.1E-08	5.1E-08	3.1E-07	4.9E-11	4.2E-06	1.0E-10	8.7E-11
6	137	27	3.6E+06	8.6E-01	1.2E+00	404800	3999.9	4.1E-06	2.0E-13	1.2E-13	8.1E-12	1.9E-12	4.6E-16	2.7E-11	5.8E-16	4.8E-16
6	138	27	3.6E+06	8.6E-01	1.2E+00	408800	4000	4.1E-06	1.9E-13	1.1E-13	8.1E-12	1.8E-12	4.4E-16	2.5E-11	5.7E-16	4.7E-16
6	139	27	3.6E+06	8.6E-01	1.2E+00	412800	3999.9	4.2E-06	1.8E-13	1.1E-13	8.1E-12	1.7E-12	4.2E-16	2.4E-11	5.5E-16	4.6E-16
6	140	27	3.6E+06	8.6E-01	1.2E+00	416800	4000	4.2E-06	1.7E-13	1.1E-13	8.1E-12	1.6E-12	4.0E-16	2.2E-11	5.4E-16	4.6E-16
6	141	27	3.6E+06	8.6E-01	1.2E+00	420800	4000.1	4.2E-06	1.6E-13	1.1E-13	8.1E-12	1.6E-12	3.9E-16	2.1E-11	5.3E-16	4.5E-16
6	142	820	9.4E+02	4.8E-04	7.5E-01	420800	20000	1.4E-04	4.6E-08	4.0E-08	8.5E-08	5.1E-07	7.6E-11	6.2E-06	1.8E-10	1.7E-10
6	143	821	7.8E+02	4.0E-04	7.5E-01	420800	20000	1.1E-04	3.8E-08	3.3E-08	7.0E-08	4.2E-07	6.2E-11	5.0E-06	1.5E-10	1.4E-10
6	144	824	4.4E+02	2.3E-04	7.5E-01	420800	20000	6.7E-05	2.2E-08	1.9E-08	4.1E-08	2.5E-07	3.6E-11	3.0E-06	8.8E-11	7.9E-11
6	145	27	3.6E+06	8.6E-01	1.2E+00	424800	4000.1	4.2E-06	1.5E-13	1.1E-13	8.1E-12	1.5E-12	3.7E-16	1.9E-11	5.1E-16	4.4E-16
6	146	27	3.6E+06	8.6E-01	1.2E+00	428800	4000	4.2E-06	1.4E-13	1.0E-13	8.1E-12	1.4E-12	3.6E-16	1.8E-11	5.0E-16	4.3E-16
6	147	27	3.6E+06	8.6E-01	1.2E+00	432800	4000	4.2E-06	1.3E-13	1.0E-13	8.1E-12	1.4E-12	3.5E-16	1.7E-11	4.9E-16	4.2E-16
6	148	27	3.6E+06	8.6E-01	1.2E+00	436800	4000	4.3E-06	1.2E-13	1.0E-13	8.1E-12	1.3E-12	3.3E-16	1.6E-11	4.8E-16	4.1E-16
6	149	27	3.6E+06	8.6E-01	1.2E+00	440800	4000	4.3E-06	1.2E-13	9.7E-14	8.1E-12	1.2E-12	3.2E-16	1.5E-11	4.6E-16	4.0E-16
6	150	820	9.7E+02	5.0E-04	7.4E-01	440800	24000	1.7E-04	3.9E-08	3.9E-08	8.2E-08	4.8E-07	6.3E-11	5.0E-06	1.8E-10	1.7E-10
6	151	821	8.0E+02	4.1E-04	7.4E-01	440800	24000	1.4E-04	3.2E-08	3.2E-08	6.8E-08	3.9E-07	5.2E-11	4.1E-06	1.5E-10	1.4E-10
6	152	824	4.6E+02	2.3E-04	7.4E-01	440800	24000	8.2E-05	1.9E-08	1.9E-08	4.0E-08	2.3E-07	3.0E-11	2.4E-06	8.7E-11	8.0E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	153	27	3.6E+06	8.6E-01	1.2E+00	444800	4000	4.3E-06	1.1E-13	9.4E-14	8.1E-12	1.2E-12	3.1E-16	1.4E-11	4.5E-16	3.9E-16
6	154	27	3.6E+06	8.6E-01	1.2E+00	448800	4000	4.3E-06	1.0E-13	9.0E-14	8.1E-12	1.1E-12	3.0E-16	1.3E-11	4.3E-16	3.8E-16
6	155	27	3.6E+06	8.6E-01	1.2E+00	452800	3999.9	4.3E-06	9.6E-14	8.7E-14	8.2E-12	1.1E-12	2.9E-16	1.2E-11	4.1E-16	3.6E-16
6	156	27	3.6E+06	8.6E-01	1.2E+00	456800	4000.1	4.4E-06	9.0E-14	8.3E-14	8.2E-12	1.0E-12	2.8E-16	1.1E-11	4.0E-16	3.5E-16
6	157	27	3.6E+06	8.6E-01	1.2E+00	460800	3999.9	4.4E-06	8.5E-14	8.0E-14	8.2E-12	9.7E-13	2.7E-16	1.0E-11	3.9E-16	3.4E-16
6	158	27	3.6E+06	8.6E-01	1.2E+00	464800	4000	4.4E-06	7.9E-14	7.7E-14	8.2E-12	9.1E-13	2.6E-16	9.4E-12	3.7E-16	3.3E-16
6	159	820	1.0E+03	5.1E-04	7.3E-01	464800	20000	1.4E-04	2.2E-08	2.7E-08	5.5E-08	2.6E-07	3.6E-11	2.7E-06	1.3E-10	1.2E-10
6	160	821	8.3E+02	4.2E-04	7.3E-01	464800	20000	1.2E-04	1.8E-08	2.3E-08	4.5E-08	2.1E-07	2.9E-11	2.2E-06	1.0E-10	9.7E-11
6	161	824	4.7E+02	2.4E-04	7.4E-01	464800	20000	6.9E-05	1.1E-08	1.3E-08	2.7E-08	1.3E-07	1.7E-11	1.3E-06	6.1E-11	5.7E-11
6	162	27	3.6E+06	8.6E-01	1.2E+00	468800	4000	4.4E-06	7.4E-14	7.5E-14	8.2E-12	8.4E-13	2.5E-16	8.7E-12	3.6E-16	3.2E-16
6	163	27	3.6E+06	8.6E-01	1.2E+00	472800	3999.9	4.4E-06	6.9E-14	7.2E-14	8.2E-12	7.8E-13	2.4E-16	8.0E-12	3.5E-16	3.1E-16
6	164	27	3.6E+06	8.6E-01	1.2E+00	476800	4000.1	4.4E-06	6.5E-14	7.0E-14	8.2E-12	7.2E-13	2.3E-16	7.3E-12	3.4E-16	3.0E-16
6	165	27	3.6E+06	8.6E-01	1.2E+00	480800	4000	4.4E-06	6.0E-14	6.9E-14	8.2E-12	6.6E-13	2.2E-16	6.8E-12	3.3E-16	2.9E-16
6	166	27	3.6E+06	8.6E-01	1.2E+00	484800	3999.9	4.5E-06	5.6E-14	6.7E-14	8.2E-12	6.1E-13	2.2E-16	6.2E-12	3.2E-16	2.9E-16
6	167	820	1.0E+03	5.2E-04	7.3E-01	484800	24000	1.8E-04	1.7E-08	2.7E-08	5.5E-08	1.9E-07	2.8E-11	2.0E-06	1.2E-10	1.2E-10
6	168	821	8.5E+02	4.3E-04	7.3E-01	484800	24000	1.4E-04	1.4E-08	2.2E-08	4.5E-08	1.6E-07	2.3E-11	1.6E-06	1.0E-10	9.7E-11
6	169	824	4.8E+02	2.4E-04	7.3E-01	484800	24000	8.5E-05	8.2E-09	1.3E-08	2.6E-08	9.2E-08	1.4E-11	9.5E-07	5.9E-11	5.7E-11
6	170	27	3.6E+06	8.6E-01	1.2E+00	488800	4000.2	4.5E-06	5.2E-14	6.4E-14	8.2E-12	5.6E-13	2.1E-16	5.7E-12	3.1E-16	2.8E-16
6	171	27	3.6E+06	8.6E-01	1.2E+00	492800	4000	4.5E-06	4.9E-14	6.2E-14	8.3E-12	5.1E-13	2.0E-16	5.2E-12	3.0E-16	2.7E-16
6	172	27	3.6E+06	8.6E-01	1.2E+00	496800	3999.8	4.5E-06	4.5E-14	5.9E-14	8.3E-12	4.7E-13	2.0E-16	4.8E-12	2.8E-16	2.6E-16
6	173	27	3.6E+06	8.6E-01	1.2E+00	500800	4000	4.5E-06	4.2E-14	5.6E-14	8.3E-12	4.3E-13	1.9E-16	4.3E-12	2.7E-16	2.5E-16
6	174	27	3.6E+06	8.6E-01	1.2E+00	504800	4000	4.5E-06	3.9E-14	5.4E-14	8.3E-12	3.9E-13	1.9E-16	4.0E-12	2.6E-16	2.4E-16
6	175	27	3.6E+06	8.6E-01	1.2E+00	508800	4000.1	4.6E-06	3.6E-14	5.2E-14	8.3E-12	3.6E-13	1.8E-16	3.6E-12	2.5E-16	2.3E-16
6	176	820	1.1E+03	5.3E-04	7.2E-01	508800	20000	1.5E-04	8.8E-09	1.8E-08	3.8E-08	9.2E-08	1.5E-11	9.4E-07	8.1E-11	7.9E-11
6	177	821	8.8E+02	4.4E-04	7.2E-01	508800	20000	1.2E-04	7.2E-09	1.5E-08	3.2E-08	7.6E-08	1.2E-11	7.8E-07	6.7E-11	6.6E-11
6	178	824	5.0E+02	2.5E-04	7.2E-01	508800	20000	7.2E-05	4.2E-09	8.6E-09	1.9E-08	4.5E-08	7.2E-12	4.6E-07	4.0E-11	3.8E-11
6	179	27	3.6E+06	8.6E-01	1.2E+00	512800	4000.1	4.6E-06	3.4E-14	5.0E-14	8.3E-12	3.2E-13	1.8E-16	3.3E-12	2.4E-16	2.2E-16
6	180	27	3.6E+06	8.6E-01	1.2E+00	516800	3999.8	4.6E-06	3.1E-14	4.8E-14	8.3E-12	2.9E-13	1.7E-16	3.0E-12	2.3E-16	2.1E-16
6	181	27	3.6E+06	8.6E-01	1.2E+00	520800	4000.1	4.6E-06	2.9E-14	4.6E-14	8.4E-12	2.7E-13	1.7E-16	2.7E-12	2.3E-16	2.1E-16

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	182	27	3.6E+06	8.6E-01	1.2E+00	524800	4000.1	4.6E-06	2.7E-14	4.4E-14	8.4E-12	2.4E-13	1.7E-16	2.4E-12	2.2E-16	2.0E-16
6	183	27	3.6E+06	8.6E-01	1.2E+00	528800	4000	4.6E-06	2.5E-14	4.1E-14	8.4E-12	2.2E-13	1.6E-16	2.2E-12	2.1E-16	1.9E-16
6	184	820	1.1E+03	5.4E-04	7.1E-01	528800	20000	1.5E-04	5.7E-09	1.3E-08	3.4E-08	5.5E-08	9.0E-12	5.6E-07	6.3E-11	6.2E-11
6	185	821	9.0E+02	4.5E-04	7.1E-01	528800	20000	1.3E-04	4.7E-09	1.1E-08	2.9E-08	4.5E-08	7.5E-12	4.7E-07	5.3E-11	5.2E-11
6	186	824	5.2E+02	2.6E-04	7.1E-01	528800	20000	7.4E-05	2.8E-09	6.3E-09	1.7E-08	2.7E-08	4.4E-12	2.7E-07	3.1E-11	3.0E-11
6	187	27	3.6E+06	8.6E-01	1.2E+00	532800	3999.8	4.6E-06	2.4E-14	3.9E-14	8.4E-12	2.0E-13	1.6E-16	2.0E-12	2.0E-16	1.8E-16
6	188	27	3.6E+06	8.6E-01	1.2E+00	536800	4000.1	4.7E-06	2.2E-14	3.6E-14	8.5E-12	1.8E-13	1.6E-16	1.8E-12	1.9E-16	1.7E-16
6	189	27	3.6E+06	8.6E-01	1.2E+00	540800	3999.9	4.7E-06	2.1E-14	3.4E-14	8.5E-12	1.6E-13	1.5E-16	1.6E-12	1.8E-16	1.6E-16
6	190	27	3.6E+06	8.6E-01	1.2E+00	544800	4000	4.7E-06	1.9E-14	3.3E-14	8.5E-12	1.5E-13	1.5E-16	1.4E-12	1.7E-16	1.5E-16
6	191	27	3.6E+06	8.6E-01	1.2E+00	548800	4000.1	4.7E-06	1.8E-14	3.2E-14	8.5E-12	1.3E-13	1.5E-16	1.3E-12	1.7E-16	1.5E-16
6	192	820	1.1E+03	5.5E-04	7.1E-01	548800	24000	1.8E-04	4.3E-09	1.4E-08	3.8E-08	3.7E-08	7.3E-12	3.8E-07	6.8E-11	6.7E-11
6	193	821	9.3E+02	4.5E-04	7.1E-01	548800	24000	1.5E-04	3.6E-09	1.2E-08	3.2E-08	3.1E-08	6.1E-12	3.2E-07	5.6E-11	5.6E-11
6	194	824	5.3E+02	2.6E-04	7.1E-01	548800	24000	9.0E-05	2.1E-09	6.9E-09	1.9E-08	1.8E-08	3.6E-12	1.9E-07	3.3E-11	3.3E-11
6	195	27	3.6E+06	8.6E-01	1.2E+00	552800	4000	4.7E-06	1.7E-14	3.1E-14	8.5E-12	1.2E-13	1.5E-16	1.2E-12	1.6E-16	1.5E-16
6	196	27	3.6E+06	8.6E-01	1.2E+00	556800	4000	4.7E-06	1.6E-14	3.0E-14	8.5E-12	1.1E-13	1.5E-16	1.0E-12	1.6E-16	1.4E-16
6	197	27	3.6E+06	8.6E-01	1.2E+00	560800	4000	4.7E-06	1.5E-14	3.0E-14	8.6E-12	9.8E-14	1.4E-16	9.4E-13	1.6E-16	1.4E-16
6	198	27	3.6E+06	8.6E-01	1.2E+00	564800	4000	4.8E-06	1.4E-14	2.9E-14	8.6E-12	8.9E-14	1.4E-16	8.5E-13	1.5E-16	1.4E-16
6	199	27	3.6E+06	8.6E-01	1.2E+00	568800	3999.9	4.8E-06	1.4E-14	2.9E-14	8.6E-12	8.1E-14	1.4E-16	7.7E-13	1.5E-16	1.4E-16
6	200	27	3.6E+06	8.6E-01	1.2E+00	572800	4000.1	4.8E-06	1.3E-14	2.8E-14	8.6E-12	7.3E-14	1.4E-16	6.9E-13	1.5E-16	1.3E-16
6	201	820	1.2E+03	5.6E-04	7.0E-01	572800	20200	1.6E-04	2.4E-09	1.1E-08	3.0E-08	1.8E-08	4.5E-12	1.8E-07	5.2E-11	5.2E-11
6	202	821	9.5E+02	4.6E-04	7.0E-01	572800	20200	1.3E-04	2.0E-09	9.1E-09	2.5E-08	1.5E-08	3.7E-12	1.5E-07	4.3E-11	4.3E-11
6	203	824	5.4E+02	2.6E-04	7.0E-01	572800	20200	7.6E-05	1.2E-09	5.3E-09	1.5E-08	8.5E-09	2.2E-12	8.7E-08	2.5E-11	2.5E-11
6	204	27	3.6E+06	8.6E-01	1.2E+00	576800	4000	4.8E-06	1.2E-14	2.8E-14	8.6E-12	6.7E-14	1.4E-16	6.2E-13	1.5E-16	1.3E-16
6	205	27	3.6E+06	8.6E-01	1.2E+00	580800	4000	4.8E-06	1.2E-14	2.8E-14	8.6E-12	6.1E-14	1.4E-16	5.6E-13	1.4E-16	1.3E-16
6	206	27	3.6E+06	8.6E-01	1.2E+00	584800	4200	5.1E-06	1.2E-14	2.8E-14	9.1E-12	5.8E-14	1.5E-16	5.3E-13	1.5E-16	1.3E-16
6	207	27	3.6E+06	8.6E-01	1.2E+00	589000	4000	4.8E-06	1.1E-14	2.6E-14	8.7E-12	5.0E-14	1.4E-16	4.5E-13	1.4E-16	1.3E-16
6	208	27	3.6E+06	8.6E-01	1.2E+00	593000	3999.9	4.9E-06	1.1E-14	2.6E-14	8.7E-12	4.6E-14	1.4E-16	4.1E-13	1.4E-16	1.2E-16
6	209	820	1.2E+03	5.7E-04	7.0E-01	593000	11800	9.3E-05	1.0E-09	5.7E-09	1.7E-08	6.7E-09	2.0E-12	6.9E-08	2.8E-11	2.8E-11
6	210	821	9.7E+02	4.7E-04	7.0E-01	593000	11800	7.7E-05	8.7E-10	4.7E-09	1.4E-08	5.6E-09	1.6E-12	5.7E-08	2.3E-11	2.3E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
6	211	824	5.5E+02	2.7E-04	7.0E-01	593000	11800	4.5E-05	5.1E-10	2.8E-09	8.5E-09	3.3E-09	9.5E-13	3.3E-08	1.4E-11	1.4E-11
6	212	27	3.6E+06	8.6E-01	1.2E+00	597000	4000.1	4.9E-06	1.0E-14	2.5E-14	8.7E-12	4.2E-14	1.4E-16	3.7E-13	1.3E-16	1.2E-16
6	213	27	3.6E+06	8.6E-01	1.2E+00	601000	3800	4.6E-06	9.3E-15	2.3E-14	8.3E-12	3.7E-14	1.3E-16	3.2E-13	1.2E-16	1.1E-16
7	1	820	3.0E+03	8.6E-04	6.5E-01	57000	22000	1.1E-04	1.8E-05	2.3E-07	2.1E-05	2.1E-05	4.8E-07	4.6E-06	9.3E-09	2.1E-10
7	2	821	2.5E+03	7.1E-04	6.5E-01	57000	22000	9.3E-05	1.5E-05	1.9E-07	1.8E-05	1.7E-05	4.0E-07	3.8E-06	7.7E-09	1.7E-10
7	3	824	1.4E+03	4.0E-04	6.5E-01	57000	22000	5.3E-05	8.6E-06	1.1E-07	1.0E-05	9.9E-06	2.3E-07	2.2E-06	4.4E-09	9.9E-11
7	4	842	2.6E+06	7.2E-01	6.9E-01	57000	4000	5.8E-03	1.7E-03	6.5E-06	1.6E-03	1.6E-03	9.0E-06	4.3E-04	1.9E-10	1.9E-10
7	5	842	3.4E+06	1.0E+00	6.2E-01	61000	3000.1	1.5E-02	3.7E-03	1.8E-05	3.8E-03	3.7E-03	4.6E-05	9.5E-04	8.6E-10	8.6E-10
7	6	842	3.0E+06	8.8E-01	6.4E-01	64000	3771.1	2.2E-02	7.2E-03	4.4E-05	8.2E-03	8.1E-03	1.8E-04	1.8E-03	3.2E-09	3.3E-09
7	7	842	3.0E+06	8.6E-01	6.3E-01	67771	3228.8	2.1E-02	5.5E-03	6.6E-05	6.9E-03	6.8E-03	2.6E-04	1.4E-03	4.9E-09	4.9E-09
7	8	842	2.9E+06	8.5E-01	6.2E-01	71000	4000.1	2.5E-02	1.9E-03	3.1E-05	2.6E-03	2.8E-03	1.0E-04	5.0E-04	2.2E-09	2.3E-09
7	9	842	3.2E+06	9.3E-01	6.0E-01	75000	4000	2.7E-02	1.1E-03	3.4E-04	2.9E-03	2.8E-03	6.3E-05	2.4E-04	3.5E-05	7.7E-07
7	10	820	3.2E+03	9.5E-04	5.9E-01	79000	19400	1.2E-04	2.9E-06	4.9E-07	3.3E-06	3.0E-06	6.1E-08	7.1E-07	4.7E-08	1.1E-09
7	11	821	2.7E+03	7.8E-04	5.9E-01	79000	19400	1.0E-04	2.4E-06	4.0E-07	2.7E-06	2.4E-06	5.1E-08	5.9E-07	3.9E-08	9.5E-10
7	12	824	1.5E+03	4.5E-04	5.9E-01	79000	19400	5.9E-05	1.4E-06	2.3E-07	1.5E-06	1.4E-06	2.9E-08	3.3E-07	2.2E-08	5.4E-10
7	13	842	3.0E+06	8.6E-01	5.6E-01	79000	2999.9	1.8E-02	5.4E-04	2.2E-04	1.6E-03	1.5E-03	2.9E-05	1.1E-04	2.3E-05	5.5E-07
7	14	842	3.0E+06	8.6E-01	5.5E-01	82000	4000	2.4E-02	3.8E-04	1.2E-04	8.5E-04	7.9E-04	1.6E-05	7.9E-05	1.2E-05	3.0E-07
7	15	842	3.0E+06	8.6E-01	5.4E-01	86000	4400.1	2.6E-02	6.9E-04	6.1E-05	4.3E-04	3.4E-04	6.7E-06	1.8E-04	5.2E-06	1.3E-07
7	16	842	3.0E+06	8.7E-01	5.3E-01	90400	4000	2.3E-02	1.0E-03	3.7E-05	2.3E-04	1.7E-04	3.1E-06	2.8E-04	2.4E-06	6.5E-08
7	17	842	3.7E+06	1.1E+00	5.3E-01	94400	4000	2.7E-02	1.1E-03	2.8E-05	2.0E-04	1.3E-04	2.2E-06	2.8E-04	1.7E-06	5.0E-08
7	18	820	3.4E+03	1.0E-03	5.4E-01	98400	24000	1.4E-04	2.3E-06	8.2E-08	1.1E-06	3.7E-07	4.7E-09	5.6E-07	3.6E-09	1.6E-10
7	19	821	2.8E+03	8.4E-04	5.4E-01	98400	24000	1.1E-04	1.9E-06	6.7E-08	8.9E-07	3.1E-07	3.9E-09	4.6E-07	3.0E-09	1.3E-10
7	20	824	1.6E+03	4.8E-04	5.4E-01	98400	24000	6.6E-05	1.1E-06	3.8E-08	5.1E-07	1.8E-07	2.2E-09	2.6E-07	1.7E-09	7.6E-11
7	21	842	3.0E+06	8.9E-01	5.2E-01	98400	4000	2.2E-02	5.6E-04	1.7E-05	1.5E-04	7.8E-05	1.2E-06	1.4E-04	9.3E-07	3.2E-08
7	22	842	3.1E+06	9.0E-01	5.2E-01	102400	4000	2.1E-02	4.2E-04	1.5E-05	1.6E-04	6.3E-05	8.9E-07	1.0E-04	6.8E-07	2.7E-08
7	23	842	3.1E+06	9.1E-01	5.1E-01	106400	3999.9	2.1E-02	3.3E-04	1.4E-05	1.7E-04	5.5E-05	6.9E-07	8.0E-05	5.3E-07	2.5E-08
7	24	842	3.1E+06	9.2E-01	5.1E-01	110400	4000	2.0E-02	2.7E-04	1.1E-05	1.7E-04	5.0E-05	5.4E-07	6.3E-05	4.2E-07	2.3E-08
7	25	842	3.1E+06	9.3E-01	5.0E-01	114400	4000.2	2.0E-02	2.2E-04	9.1E-06	1.8E-04	4.7E-05	4.3E-07	5.1E-05	3.4E-07	2.2E-08
7	26	842	3.1E+06	9.4E-01	5.0E-01	118400	3999.9	1.9E-02	1.9E-04	7.4E-06	1.9E-04	4.6E-05	3.5E-07	4.1E-05	2.8E-07	2.0E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7	27	820	3.6E+03	1.1E-03	5.1E-01	122400	20000	1.0E-04	6.9E-07	2.6E-08	9.9E-07	2.4E-07	1.2E-09	1.4E-07	9.4E-10	9.6E-11
7	28	821	3.0E+03	9.0E-04	5.1E-01	122400	20000	8.5E-05	5.7E-07	2.1E-08	8.2E-07	2.0E-07	9.5E-10	1.1E-07	7.7E-10	7.9E-11
7	29	842	3.2E+06	9.5E-01	4.9E-01	122400	4000	1.9E-02	1.6E-04	6.1E-06	2.0E-04	4.5E-05	2.8E-07	3.3E-05	2.3E-07	1.9E-08
7	30	842	3.2E+06	9.5E-01	4.9E-01	126400	4000.1	1.8E-02	1.4E-04	5.1E-06	2.0E-04	4.4E-05	2.3E-07	2.7E-05	1.9E-07	1.8E-08
7	31	842	3.2E+06	9.6E-01	4.8E-01	130400	4000	1.8E-02	1.2E-04	4.3E-06	1.8E-04	4.3E-05	1.9E-07	2.2E-05	1.6E-07	1.7E-08
7	32	842	3.2E+06	9.7E-01	4.8E-01	134400	4000.1	1.7E-02	9.9E-05	3.7E-06	1.7E-04	4.3E-05	1.6E-07	1.9E-05	1.3E-07	1.6E-08
7	33	842	3.2E+06	9.8E-01	4.8E-01	138400	3999.8	1.7E-02	8.5E-05	3.2E-06	1.5E-04	4.1E-05	1.3E-07	1.6E-05	1.1E-07	1.6E-08
7	34	820	3.8E+03	1.2E-03	4.9E-01	142400	24000	1.1E-04	3.9E-07	1.6E-08	8.5E-07	2.5E-07	5.3E-10	6.6E-08	4.9E-10	9.5E-11
7	35	821	3.1E+03	9.6E-04	4.9E-01	142400	24000	8.9E-05	3.2E-07	1.3E-08	7.0E-07	2.0E-07	4.4E-10	5.5E-08	4.0E-10	7.9E-11
7	36	824	1.8E+03	5.5E-04	4.9E-01	142400	24000	5.1E-05	1.9E-07	7.4E-09	4.0E-07	1.2E-07	2.5E-10	3.1E-08	2.3E-10	4.5E-11
7	37	842	3.3E+06	9.9E-01	4.7E-01	142400	4000	1.7E-02	7.4E-05	2.8E-06	1.4E-04	4.0E-05	1.1E-07	1.3E-05	9.5E-08	1.5E-08
7	38	842	3.3E+06	1.0E+00	4.7E-01	146400	4000	1.6E-02	6.5E-05	2.6E-06	1.3E-04	3.8E-05	9.2E-08	1.1E-05	8.2E-08	1.5E-08
7	39	842	3.3E+06	1.0E+00	4.7E-01	150400	4000.1	1.6E-02	5.8E-05	2.3E-06	1.3E-04	3.7E-05	7.8E-08	9.7E-06	7.1E-08	1.4E-08
7	40	842	3.3E+06	1.0E+00	4.6E-01	154400	3999.9	1.5E-02	5.2E-05	2.1E-06	1.2E-04	3.6E-05	6.7E-08	8.4E-06	6.3E-08	1.4E-08
7	41	842	3.3E+06	1.0E+00	4.6E-01	158400	3999.9	1.5E-02	4.7E-05	2.0E-06	1.2E-04	3.4E-05	5.7E-08	7.3E-06	5.6E-08	1.4E-08
7	42	842	3.4E+06	1.0E+00	4.6E-01	162400	4000.1	1.4E-02	4.3E-05	1.9E-06	1.2E-04	3.3E-05	4.9E-08	6.4E-06	5.0E-08	1.3E-08
7	43	820	3.9E+03	1.2E-03	4.8E-01	166400	18400	7.2E-05	1.8E-07	8.7E-09	6.2E-07	1.5E-07	1.9E-10	2.5E-08	2.0E-10	6.6E-11
7	44	821	3.2E+03	1.0E-03	4.8E-01	166400	18400	6.0E-05	1.5E-07	7.2E-09	5.1E-07	1.2E-07	1.5E-10	2.1E-08	1.7E-10	5.5E-11
7	45	842	3.4E+06	1.0E+00	4.6E-01	166400	4000	1.4E-02	3.9E-05	1.8E-06	1.2E-04	3.1E-05	4.3E-08	5.7E-06	4.4E-08	1.3E-08
7	46	842	3.4E+06	1.1E+00	4.6E-01	170400	2399.9	8.2E-03	2.2E-05	1.0E-06	7.1E-05	1.7E-05	2.3E-08	3.1E-06	2.5E-08	7.7E-09
7	47	842	3.4E+06	1.1E+00	4.5E-01	172800	4000.1	1.3E-02	3.5E-05	1.7E-06	1.2E-04	2.7E-05	3.5E-08	4.7E-06	3.8E-08	1.3E-08
7	48	842	3.4E+06	1.1E+00	4.5E-01	176800	3999.9	1.3E-02	3.2E-05	1.6E-06	1.2E-04	2.5E-05	3.0E-08	4.2E-06	3.4E-08	1.2E-08
7	49	842	3.4E+06	1.1E+00	4.5E-01	180800	4000.1	1.3E-02	3.0E-05	1.5E-06	1.2E-04	2.4E-05	2.7E-08	3.8E-06	3.1E-08	1.2E-08
7	50	820	4.0E+03	1.3E-03	4.6E-01	184800	24000	8.1E-05	1.7E-07	9.8E-09	8.7E-07	1.4E-07	1.3E-10	1.9E-08	1.7E-10	7.9E-11
7	51	821	3.3E+03	1.1E-03	4.6E-01	184800	24000	6.7E-05	1.4E-07	8.1E-09	7.2E-07	1.1E-07	1.0E-10	1.6E-08	1.4E-10	6.5E-11
7	52	842	3.5E+06	1.1E+00	4.5E-01	184800	4000.1	1.2E-02	2.8E-05	1.5E-06	1.2E-04	2.2E-05	2.3E-08	3.4E-06	2.9E-08	1.2E-08
7	53	842	3.5E+06	1.1E+00	4.5E-01	188800	4000	1.2E-02	2.7E-05	1.5E-06	1.2E-04	2.1E-05	2.1E-08	3.1E-06	2.7E-08	1.2E-08
7	54	842	3.5E+06	1.1E+00	4.4E-01	192800	3999.8	1.2E-02	2.5E-05	1.4E-06	1.3E-04	2.0E-05	1.8E-08	2.8E-06	2.5E-08	1.1E-08
7	55	842	3.5E+06	1.1E+00	4.4E-01	196800	4000.2	1.1E-02	2.4E-05	1.4E-06	1.3E-04	1.9E-05	1.6E-08	2.5E-06	2.3E-08	1.1E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7	56	842	3.5E+06	1.1E+00	4.4E-01	200800	3999.8	1.1E-02	2.3E-05	1.4E-06	1.3E-04	1.9E-05	1.4E-08	2.3E-06	2.1E-08	1.1E-08
7	57	842	3.5E+06	1.1E+00	4.4E-01	204800	4000.2	1.1E-02	2.1E-05	1.3E-06	1.3E-04	1.8E-05	1.3E-08	2.1E-06	2.0E-08	1.1E-08
7	58	820	4.2E+03	1.3E-03	4.5E-01	208800	20000	5.8E-05	1.1E-07	7.5E-09	7.7E-07	9.8E-08	5.6E-11	9.7E-09	1.0E-10	6.0E-11
7	59	842	3.5E+06	1.1E+00	4.4E-01	208800	4000	1.0E-02	2.1E-05	1.3E-06	1.3E-04	1.8E-05	1.1E-08	1.9E-06	1.9E-08	1.1E-08
7	60	842	3.5E+06	1.1E+00	4.4E-01	212800	4000	1.0E-02	2.0E-05	1.3E-06	1.3E-04	1.7E-05	1.0E-08	1.8E-06	1.8E-08	1.0E-08
7	61	842	3.6E+06	1.1E+00	4.4E-01	216800	4000	9.7E-03	1.9E-05	1.3E-06	1.3E-04	1.7E-05	9.0E-09	1.6E-06	1.7E-08	1.0E-08
7	62	842	3.6E+06	1.1E+00	4.3E-01	220800	3999.9	9.4E-03	1.8E-05	1.3E-06	1.3E-04	1.7E-05	8.1E-09	1.5E-06	1.6E-08	1.0E-08
7	63	842	3.6E+06	1.1E+00	4.3E-01	224800	4000.1	9.1E-03	1.7E-05	1.3E-06	1.3E-04	1.6E-05	7.3E-09	1.4E-06	1.5E-08	1.0E-08
7	64	820	4.3E+03	1.4E-03	4.5E-01	228800	24000	5.9E-05	1.1E-07	8.7E-09	8.7E-07	1.2E-07	3.7E-11	7.4E-09	9.2E-11	6.7E-11
7	65	842	3.6E+06	1.1E+00	4.3E-01	228800	3999.9	8.8E-03	1.7E-05	1.3E-06	1.3E-04	1.6E-05	6.6E-09	1.2E-06	1.4E-08	9.8E-09
7	66	842	3.6E+06	1.2E+00	4.3E-01	232800	3999.9	8.6E-03	1.6E-05	1.2E-06	1.3E-04	1.6E-05	5.9E-09	1.2E-06	1.4E-08	9.7E-09
7	67	842	3.6E+06	1.2E+00	4.3E-01	236800	4000.1	8.3E-03	1.5E-05	1.2E-06	1.2E-04	1.7E-05	5.3E-09	1.1E-06	1.3E-08	9.5E-09
7	68	842	3.6E+06	1.2E+00	4.3E-01	240800	4000	8.1E-03	1.5E-05	1.2E-06	1.2E-04	1.7E-05	4.8E-09	9.8E-07	1.3E-08	9.4E-09
7	69	842	3.6E+06	1.2E+00	4.3E-01	244800	4000.1	7.8E-03	1.4E-05	1.2E-06	1.2E-04	1.7E-05	4.3E-09	9.1E-07	1.2E-08	9.3E-09
7	70	842	3.7E+06	1.2E+00	4.3E-01	248800	3999.8	7.6E-03	1.3E-05	1.3E-06	1.2E-04	1.7E-05	3.9E-09	8.4E-07	1.2E-08	9.1E-09
7	71	842	3.7E+06	1.2E+00	4.3E-01	252800	4000.1	7.4E-03	1.3E-05	1.3E-06	1.2E-04	1.8E-05	3.6E-09	7.8E-07	1.1E-08	9.0E-09
7	72	842	3.7E+06	1.2E+00	4.3E-01	256800	4000	7.1E-03	1.2E-05	1.3E-06	1.1E-04	1.9E-05	3.1E-09	7.2E-07	1.1E-08	8.9E-09
7	73	842	3.7E+06	1.2E+00	4.3E-01	260800	4000.1	6.9E-03	1.2E-05	1.3E-06	1.1E-04	2.0E-05	2.9E-09	6.7E-07	1.1E-08	8.8E-09
7	74	842	3.7E+06	1.2E+00	4.3E-01	264800	4000	6.7E-03	1.1E-05	1.4E-06	1.1E-04	2.1E-05	2.6E-09	6.2E-07	1.0E-08	8.8E-09
7	75	842	3.7E+06	1.2E+00	4.3E-01	268800	3999.8	6.5E-03	1.1E-05	1.4E-06	1.0E-04	2.3E-05	2.4E-09	5.8E-07	1.0E-08	8.7E-09
7	76	842	3.7E+06	1.2E+00	4.2E-01	272800	4000.2	6.3E-03	2.8E-05	1.9E-06	1.2E-04	4.5E-05	5.6E-07	5.3E-06	4.1E-08	8.8E-09
7	77	842	3.6E+06	1.2E+00	4.2E-01	276800	3999.8	6.1E-03	2.6E-05	1.9E-06	1.1E-04	4.5E-05	4.9E-07	4.7E-06	3.7E-08	8.4E-09
7	78	842	3.6E+06	1.2E+00	4.2E-01	280800	4000.1	5.9E-03	2.4E-05	2.1E-06	1.1E-04	4.8E-05	4.5E-07	4.5E-06	3.5E-08	8.5E-09
7	79	842	3.5E+06	1.1E+00	4.2E-01	284800	4000	5.8E-03	2.3E-05	2.2E-06	1.0E-04	5.3E-05	4.1E-07	4.7E-06	3.3E-08	8.6E-09
7	80	842	3.5E+06	1.1E+00	4.2E-01	288800	4000.1	5.6E-03	2.7E-05	2.5E-06	1.1E-04	7.1E-05	5.6E-07	7.4E-06	4.0E-08	8.8E-09
7	81	820	3.7E+03	1.2E-03	4.2E-01	292800	24000	3.5E-05	2.7E-07	1.7E-08	5.2E-07	5.3E-07	5.5E-09	5.2E-05	3.6E-10	4.3E-11
7	82	821	3.1E+03	1.0E-03	4.2E-01	292800	24000	2.9E-05	2.2E-07	1.4E-08	4.3E-07	4.4E-07	4.5E-09	4.3E-05	2.9E-10	3.6E-11
7	83	824	1.8E+03	5.7E-04	4.2E-01	292800	24000	1.7E-05	1.3E-07	8.0E-09	2.5E-07	2.5E-07	2.6E-09	2.5E-05	1.7E-10	2.0E-11
7	84	842	3.4E+06	1.1E+00	4.1E-01	292800	4000	5.4E-03	3.9E-05	2.8E-06	1.1E-04	1.2E-04	9.4E-07	1.8E-02	6.1E-08	8.4E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7	85	842	3.4E+06	1.1E+00	4.1E-01	296800	3999.8	5.2E-03	5.9E-05	3.1E-06	1.1E-04	1.3E-04	1.5E-06	1.2E-02	9.3E-08	7.8E-09
7	86	842	3.3E+06	1.1E+00	4.1E-01	300800	4000.2	5.1E-03	4.4E-05	2.5E-06	8.4E-05	8.5E-05	9.7E-07	7.4E-03	6.2E-08	6.1E-09
7	87	842	3.2E+06	1.0E+00	4.1E-01	304800	3999.8	4.9E-03	3.6E-05	2.4E-06	6.4E-05	6.1E-05	6.7E-07	5.0E-03	4.4E-08	5.6E-09
7	88	842	3.1E+06	1.0E+00	4.0E-01	308800	4000.2	4.8E-03	3.4E-05	2.4E-06	5.1E-05	4.5E-05	5.0E-07	3.7E-03	3.4E-08	5.6E-09
7	89	842	3.0E+06	9.7E-01	4.0E-01	312800	3999.9	4.6E-03	3.5E-05	2.4E-06	4.2E-05	3.5E-05	3.9E-07	2.8E-03	2.8E-08	5.7E-09
7	90	820	3.2E+03	1.0E-03	4.2E-01	316800	20000	2.4E-05	2.7E-07	1.6E-08	1.9E-07	1.2E-07	1.4E-09	9.0E-06	1.2E-10	3.7E-11
7	91	821	2.6E+03	8.4E-04	4.2E-01	316800	20000	2.0E-05	2.2E-07	1.3E-08	1.6E-07	9.8E-08	1.2E-09	7.5E-06	9.7E-11	3.1E-11
7	92	824	1.5E+03	4.8E-04	4.2E-01	316800	20000	1.1E-05	1.3E-07	7.3E-09	9.0E-08	5.6E-08	6.6E-10	4.3E-06	5.5E-11	1.8E-11
7	93	842	3.0E+06	9.4E-01	4.0E-01	316800	4000	4.5E-03	3.8E-05	2.4E-06	3.8E-05	2.8E-05	3.2E-07	2.2E-03	2.4E-08	5.8E-09
7	94	842	2.9E+06	9.2E-01	4.0E-01	320800	4000.1	4.3E-03	4.3E-05	2.6E-06	3.5E-05	2.3E-05	2.7E-07	1.8E-03	2.2E-08	6.2E-09
7	95	842	2.8E+06	9.0E-01	4.0E-01	324800	3999.8	4.2E-03	5.0E-05	2.9E-06	3.4E-05	2.0E-05	2.3E-07	1.5E-03	2.0E-08	6.9E-09
7	96	842	2.8E+06	8.7E-01	4.0E-01	328800	4000.2	4.1E-03	5.8E-05	3.2E-06	3.2E-05	1.7E-05	2.1E-07	1.2E-03	1.9E-08	7.6E-09
7	97	842	2.7E+06	8.5E-01	4.0E-01	332800	4000	3.9E-03	6.7E-05	3.4E-06	3.1E-05	1.5E-05	1.9E-07	1.1E-03	1.9E-08	8.4E-09
7	98	820	2.7E+03	8.6E-04	4.1E-01	336800	24000	2.3E-05	6.7E-07	2.6E-08	2.1E-07	7.2E-08	9.5E-10	4.5E-06	1.2E-10	6.8E-11
7	99	821	2.2E+03	7.1E-04	4.1E-01	336800	24000	1.9E-05	5.5E-07	2.2E-08	1.7E-07	5.9E-08	7.8E-10	3.7E-06	9.9E-11	5.6E-11
7	100	842	2.6E+06	8.3E-01	4.0E-01	336800	3999.9	3.8E-03	7.7E-05	3.7E-06	3.1E-05	1.3E-05	1.7E-07	9.1E-04	1.9E-08	9.1E-09
7	101	842	2.6E+06	8.1E-01	4.0E-01	340800	3999.9	3.7E-03	8.9E-05	3.9E-06	3.1E-05	1.2E-05	1.6E-07	7.9E-04	1.9E-08	9.8E-09
7	102	842	2.5E+06	7.9E-01	3.9E-01	344800	4000.1	3.6E-03	1.0E-04	4.1E-06	3.2E-05	1.1E-05	1.5E-07	7.0E-04	1.9E-08	1.0E-08
7	103	842	2.4E+06	7.7E-01	3.9E-01	348800	4000.1	3.5E-03	1.1E-04	4.3E-06	3.3E-05	1.0E-05	1.4E-07	6.1E-04	1.9E-08	1.1E-08
7	104	842	2.4E+06	7.5E-01	3.9E-01	352800	3999.9	3.3E-03	1.3E-04	4.4E-06	3.4E-05	9.6E-06	1.3E-07	5.5E-04	1.9E-08	1.2E-08
7	105	842	2.3E+06	7.3E-01	3.9E-01	356800	4000.1	3.2E-03	1.4E-04	4.6E-06	3.5E-05	9.1E-06	1.2E-07	4.9E-04	1.9E-08	1.3E-08
7	106	842	2.3E+06	7.1E-01	3.9E-01	360800	3999.8	3.1E-03	1.6E-04	4.7E-06	3.6E-05	8.8E-06	1.2E-07	4.4E-04	1.9E-08	1.3E-08
7	107	842	2.2E+06	6.9E-01	3.9E-01	364800	4000.1	3.0E-03	1.7E-04	4.8E-06	3.8E-05	8.7E-06	1.3E-07	3.9E-04	1.9E-08	1.4E-08
7	108	842	2.2E+06	6.7E-01	3.9E-01	368800	4000	2.9E-03	1.9E-04	4.9E-06	3.9E-05	8.7E-06	1.2E-07	3.5E-04	1.9E-08	1.4E-08
7	109	842	2.1E+06	6.6E-01	3.9E-01	372800	4000	2.8E-03	2.0E-04	4.9E-06	4.2E-05	8.8E-06	1.2E-07	3.2E-04	2.0E-08	1.5E-08
7	110	842	2.1E+06	6.4E-01	3.9E-01	376800	4000	2.7E-03	2.1E-04	5.0E-06	4.4E-05	9.0E-06	1.1E-07	2.9E-04	2.0E-08	1.5E-08
7	111	842	2.0E+06	6.2E-01	3.9E-01	380800	3999.9	2.7E-03	2.3E-04	5.0E-06	4.8E-05	9.1E-06	1.0E-07	2.7E-04	2.1E-08	1.6E-08
7	112	842	2.0E+06	6.1E-01	3.9E-01	384800	4000.1	2.6E-03	2.4E-04	5.0E-06	5.8E-05	9.5E-06	9.5E-08	2.5E-04	2.1E-08	1.6E-08
7	113	842	1.9E+06	5.9E-01	3.9E-01	388800	4000	2.5E-03	2.5E-04	5.0E-06	1.0E-04	1.0E-05	8.6E-08	2.3E-04	2.1E-08	1.7E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7	114	842	1.9E+06	5.8E-01	3.8E-01	392800	4000	2.4E-03	2.7E-04	5.0E-06	1.5E-04	1.1E-05	7.8E-08	2.1E-04	2.1E-08	1.7E-08
7	115	842	1.8E+06	5.7E-01	3.8E-01	396800	3999.9	2.3E-03	2.8E-04	5.0E-06	2.0E-04	1.3E-05	7.0E-08	1.9E-04	2.1E-08	1.8E-08
7	116	842	1.8E+06	5.5E-01	3.8E-01	400800	4000	2.2E-03	2.6E-04	4.9E-06	2.2E-04	1.5E-05	6.2E-08	1.7E-04	2.1E-08	1.8E-08
7	117	842	1.7E+06	5.4E-01	3.8E-01	404800	4000.1	2.2E-03	2.2E-04	4.7E-06	2.0E-04	1.7E-05	5.5E-08	1.5E-04	2.0E-08	1.8E-08
7	118	842	1.7E+06	5.3E-01	3.8E-01	408800	4000	2.1E-03	2.0E-04	4.5E-06	1.8E-04	1.9E-05	4.9E-08	1.3E-04	2.0E-08	1.8E-08
7	119	842	1.7E+06	5.1E-01	3.8E-01	412800	3999.9	2.0E-03	1.7E-04	4.3E-06	1.7E-04	2.2E-05	4.3E-08	1.1E-04	2.0E-08	1.9E-08
7	120	842	1.6E+06	5.0E-01	3.8E-01	416800	4000.2	2.0E-03	1.5E-04	4.1E-06	1.5E-04	2.6E-05	3.8E-08	9.9E-05	2.0E-08	1.9E-08
7	121	842	1.6E+06	4.9E-01	3.8E-01	420800	3999.9	1.9E-03	1.3E-04	3.9E-06	1.4E-04	3.1E-05	3.3E-08	8.6E-05	2.0E-08	1.9E-08
7	122	842	1.6E+06	4.8E-01	3.8E-01	424800	4000	1.8E-03	1.2E-04	3.6E-06	1.3E-04	3.7E-05	2.9E-08	7.4E-05	1.9E-08	1.8E-08
7	123	842	1.5E+06	4.7E-01	3.7E-01	428800	4000	1.8E-03	1.0E-04	3.4E-06	1.3E-04	4.4E-05	2.5E-08	6.4E-05	1.9E-08	1.7E-08
7	124	842	1.5E+06	4.6E-01	3.7E-01	432800	4000.1	1.7E-03	8.8E-05	3.2E-06	1.2E-04	5.2E-05	2.2E-08	5.5E-05	1.9E-08	1.6E-08
7	125	842	1.5E+06	4.5E-01	3.7E-01	436800	3999.8	1.7E-03	7.7E-05	3.2E-06	1.1E-04	6.1E-05	2.0E-08	4.8E-05	2.0E-08	1.6E-08
7	126	842	1.4E+06	4.4E-01	3.7E-01	440800	4000.1	1.6E-03	6.7E-05	3.1E-06	1.1E-04	7.2E-05	1.7E-08	4.1E-05	2.0E-08	1.5E-08
7	127	842	1.4E+06	4.3E-01	3.7E-01	444800	3999.9	1.6E-03	5.9E-05	3.1E-06	1.1E-04	8.3E-05	1.5E-08	3.5E-05	2.1E-08	1.6E-08
7	128	842	1.4E+06	4.2E-01	3.7E-01	448800	4000.1	1.5E-03	5.2E-05	3.1E-06	1.0E-04	9.5E-05	1.3E-08	3.0E-05	2.3E-08	1.6E-08
7	129	842	1.3E+06	4.1E-01	3.7E-01	452800	3999.9	1.5E-03	4.6E-05	3.1E-06	1.0E-04	1.0E-04	1.2E-08	2.6E-05	2.4E-08	1.5E-08
7	130	842	1.3E+06	4.0E-01	3.7E-01	456800	4000.1	1.4E-03	4.1E-05	3.4E-06	1.0E-04	1.1E-04	1.0E-08	2.2E-05	2.5E-08	1.5E-08
7	131	842	1.3E+06	3.9E-01	3.7E-01	460800	3999.9	1.4E-03	3.7E-05	4.2E-06	1.0E-04	1.3E-04	9.2E-09	1.9E-05	2.7E-08	1.5E-08
7	132	842	1.3E+06	3.8E-01	3.7E-01	464800	4000.1	1.3E-03	3.4E-05	4.9E-06	9.9E-05	1.5E-04	8.1E-09	1.6E-05	2.8E-08	1.5E-08
7	133	842	1.2E+06	3.7E-01	3.7E-01	468800	4000	1.3E-03	3.1E-05	4.6E-06	9.9E-05	1.6E-04	7.2E-09	1.4E-05	3.0E-08	1.5E-08
7	134	842	1.2E+06	3.7E-01	3.7E-01	472800	3999.9	1.2E-03	2.8E-05	4.6E-06	9.9E-05	1.7E-04	6.3E-09	1.2E-05	3.3E-08	1.5E-08
7	135	842	1.2E+06	3.6E-01	3.7E-01	476800	4000.1	1.2E-03	2.6E-05	4.8E-06	9.9E-05	1.9E-04	5.7E-09	1.0E-05	3.5E-08	1.5E-08
7	136	842	1.2E+06	3.5E-01	3.6E-01	480800	4000	1.2E-03	2.5E-05	5.2E-06	9.8E-05	2.1E-04	5.1E-09	8.6E-06	3.8E-08	1.4E-08
7	137	842	1.1E+06	3.4E-01	3.6E-01	484800	3999.9	1.1E-03	2.4E-05	6.7E-06	9.7E-05	2.3E-04	4.5E-09	7.5E-06	4.2E-08	1.4E-08
7	138	842	1.1E+06	3.4E-01	3.6E-01	488800	4000.1	1.1E-03	2.3E-05	8.3E-06	9.7E-05	2.6E-04	4.1E-09	6.6E-06	4.7E-08	1.4E-08
7	139	842	1.1E+06	3.3E-01	3.6E-01	492800	4000	1.0E-03	2.2E-05	1.0E-05	9.5E-05	2.8E-04	3.8E-09	5.8E-06	5.2E-08	1.4E-08
7	140	842	1.1E+06	3.2E-01	3.6E-01	496800	1199.9	3.0E-04	6.3E-06	3.4E-06	2.7E-05	8.9E-05	1.0E-09	1.6E-06	1.6E-08	4.1E-09
7	141	842	1.0E+06	3.1E-01	3.6E-01	498000	4000.1	9.6E-04	2.0E-05	1.2E-05	8.5E-05	3.1E-04	3.5E-09	4.9E-06	5.7E-08	1.3E-08
7	142	842	9.8E+05	2.9E-01	3.6E-01	502000	4000	9.0E-04	2.0E-05	1.4E-05	7.8E-05	3.4E-04	3.1E-09	4.4E-06	6.2E-08	1.2E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7	143	842	9.3E+05	2.8E-01	3.6E-01	506000	3999.9	8.4E-04	1.9E-05	1.5E-05	7.2E-05	3.2E-04	2.9E-09	4.0E-06	6.7E-08	1.2E-08
7	144	842	8.8E+05	2.6E-01	3.6E-01	510000	4000.1	7.9E-04	1.8E-05	1.6E-05	6.7E-05	2.9E-04	2.9E-09	3.7E-06	7.3E-08	1.1E-08
7	145	842	8.4E+05	2.5E-01	3.6E-01	514000	4000	7.4E-04	1.8E-05	1.5E-05	6.3E-05	2.6E-04	2.7E-09	3.4E-06	8.0E-08	1.1E-08
7	146	842	8.0E+05	2.4E-01	3.5E-01	518000	4000	7.0E-04	1.8E-05	1.3E-05	5.9E-05	2.4E-04	2.8E-09	3.4E-06	8.7E-08	1.0E-08
7	147	842	7.7E+05	2.3E-01	3.5E-01	522000	4000	6.6E-04	1.8E-05	1.1E-05	5.6E-05	2.3E-04	2.7E-09	3.4E-06	9.5E-08	9.6E-09
7	148	842	7.4E+05	2.2E-01	3.5E-01	526000	4000	6.2E-04	1.9E-05	1.0E-05	5.3E-05	2.2E-04	2.9E-09	3.6E-06	1.0E-07	8.8E-09
7	149	842	7.0E+05	2.1E-01	3.5E-01	530000	4000	5.9E-04	2.0E-05	9.6E-06	5.1E-05	2.2E-04	3.0E-09	3.8E-06	1.1E-07	8.2E-09
7	150	842	6.7E+05	2.0E-01	3.5E-01	534000	4000	5.5E-04	2.0E-05	9.0E-06	4.9E-05	2.1E-04	3.3E-09	3.8E-06	1.2E-07	8.3E-09
7	151	842	6.5E+05	1.9E-01	3.4E-01	538000	3999.9	5.3E-04	2.0E-05	8.1E-06	4.7E-05	2.1E-04	3.6E-09	3.9E-06	1.3E-07	7.8E-09
7	152	842	6.3E+05	1.8E-01	3.4E-01	542000	4000.1	5.0E-04	2.0E-05	7.3E-06	4.5E-05	2.0E-04	4.0E-09	4.0E-06	1.4E-07	7.7E-09
7	153	842	6.1E+05	1.8E-01	3.4E-01	546000	4000	4.7E-04	2.1E-05	6.8E-06	4.4E-05	1.6E-04	4.3E-09	4.1E-06	1.4E-07	7.5E-09
7	154	842	5.9E+05	1.7E-01	3.4E-01	550000	4000	4.5E-04	2.1E-05	6.3E-06	4.2E-05	1.4E-04	4.7E-09	4.3E-06	1.2E-07	7.4E-09
7	155	842	5.7E+05	1.7E-01	3.4E-01	554000	4000	4.3E-04	2.1E-05	5.7E-06	4.1E-05	1.1E-04	5.2E-09	4.3E-06	1.0E-07	7.5E-09
7	156	842	5.5E+05	1.6E-01	3.4E-01	558000	3999.9	4.1E-04	2.1E-05	5.3E-06	4.0E-05	9.4E-05	5.6E-09	4.3E-06	8.5E-08	7.5E-09
7	157	842	5.4E+05	1.6E-01	3.4E-01	562000	4000	4.0E-04	2.2E-05	4.8E-06	3.9E-05	8.0E-05	6.2E-09	4.5E-06	7.2E-08	7.3E-09
7	158	842	5.3E+05	1.6E-01	3.4E-01	566000	4000.1	3.9E-04	2.3E-05	4.5E-06	3.8E-05	6.8E-05	6.7E-09	4.9E-06	6.1E-08	6.8E-09
7	159	842	5.2E+05	1.5E-01	3.3E-01	570000	4000	3.7E-04	2.2E-05	4.2E-06	3.8E-05	5.7E-05	7.2E-09	4.5E-06	5.1E-08	6.3E-09
7	160	842	5.1E+05	1.5E-01	3.3E-01	574000	4000	3.6E-04	1.9E-05	3.9E-06	3.7E-05	4.8E-05	8.0E-09	3.8E-06	4.4E-08	6.2E-09
7	161	842	5.0E+05	1.5E-01	3.3E-01	578000	4000	3.5E-04	1.7E-05	3.6E-06	3.7E-05	4.1E-05	8.5E-09	3.3E-06	3.7E-08	6.2E-09
7	162	842	4.9E+05	1.4E-01	3.3E-01	582000	4000	3.4E-04	1.6E-05	3.4E-06	3.6E-05	3.5E-05	9.1E-09	2.9E-06	3.2E-08	6.0E-09
7	163	842	4.9E+05	1.4E-01	3.3E-01	586000	4000	3.3E-04	1.5E-05	3.2E-06	3.6E-05	3.0E-05	9.9E-09	2.6E-06	2.8E-08	5.7E-09
7	164	842	4.8E+05	1.4E-01	3.3E-01	590000	4000	3.2E-04	1.4E-05	2.9E-06	3.6E-05	2.6E-05	1.0E-08	2.4E-06	2.4E-08	5.4E-09
7	165	842	4.8E+05	1.4E-01	3.2E-01	594000	4000	3.1E-04	1.3E-05	2.7E-06	3.6E-05	2.3E-05	1.1E-08	2.2E-06	2.1E-08	5.1E-09
7	166	842	4.7E+05	1.3E-01	3.2E-01	598000	3999.9	3.0E-04	1.3E-05	2.6E-06	3.6E-05	2.0E-05	1.2E-08	2.1E-06	1.8E-08	5.0E-09
7	167	842	4.6E+05	1.3E-01	3.2E-01	602000	2800.1	2.1E-04	8.8E-06	1.7E-06	2.5E-05	1.2E-05	8.8E-09	1.4E-06	1.1E-08	3.6E-09
7A	1	820	3.0E+03	8.6E-04	6.5E-01	57000	22000	1.1E-04	1.8E-05	1.9E-07	2.1E-05	2.0E-05	4.7E-07	4.6E-06	6.0E-09	1.4E-10
7A	2	821	2.5E+03	7.1E-04	6.5E-01	57000	22000	9.3E-05	1.5E-05	1.6E-07	1.7E-05	1.7E-05	3.9E-07	3.8E-06	5.0E-09	1.2E-10
7A	3	824	1.4E+03	4.0E-04	6.5E-01	57000	22000	5.3E-05	8.5E-06	9.1E-08	9.8E-06	9.6E-06	2.2E-07	2.2E-06	2.9E-09	6.6E-11
7A	4	842	2.6E+06	7.2E-01	6.9E-01	57000	4000	5.8E-03	1.7E-03	6.5E-06	1.6E-03	1.6E-03	9.0E-06	4.3E-04	1.9E-10	1.9E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	5	842	3.4E+06	1.0E+00	6.2E-01	61000	3000.1	1.5E-02	3.7E-03	1.8E-05	3.8E-03	3.7E-03	4.6E-05	9.5E-04	8.6E-10	8.6E-10
7A	6	842	3.0E+06	8.8E-01	6.4E-01	64000	3771.1	2.2E-02	7.2E-03	4.4E-05	8.2E-03	8.1E-03	1.8E-04	1.8E-03	3.2E-09	3.3E-09
7A	7	842	3.0E+06	8.6E-01	6.3E-01	67771	3228.8	2.1E-02	5.5E-03	6.6E-05	6.9E-03	6.8E-03	2.6E-04	1.4E-03	4.9E-09	4.9E-09
7A	8	842	2.9E+06	8.5E-01	6.2E-01	71000	4000.1	2.5E-02	1.9E-03	3.1E-05	2.6E-03	2.8E-03	1.0E-04	5.0E-04	2.2E-09	2.3E-09
7A	9	842	2.5E+06	7.2E-01	6.2E-01	75000	3999.9	2.1E-02	7.1E-04	1.4E-04	2.0E-03	1.8E-03	3.9E-05	1.6E-04	1.4E-05	3.0E-07
7A	10	820	3.2E+03	9.5E-04	6.2E-01	79000	19400	1.3E-04	1.1E-06	9.1E-08	5.6E-07	4.8E-07	7.1E-09	2.8E-07	8.5E-09	2.2E-10
7A	11	821	2.7E+03	7.8E-04	6.2E-01	79000	19400	1.1E-04	8.8E-07	7.5E-08	4.6E-07	4.0E-07	5.9E-09	2.3E-07	7.0E-09	1.8E-10
7A	12	824	1.5E+03	4.5E-04	6.2E-01	79000	19400	6.1E-05	5.0E-07	4.3E-08	2.6E-07	2.3E-07	3.4E-09	1.3E-07	4.0E-09	1.1E-10
7A	13	842	6.8E+05	2.0E-01	6.0E-01	79000	3000	4.0E-03	2.2E-05	1.1E-05	8.1E-05	7.5E-05	9.0E-07	4.0E-06	1.1E-06	3.0E-08
7A	14	842	5.1E+05	1.5E-01	6.0E-01	82000	4000	4.0E-03	2.1E-05	2.3E-06	1.7E-05	1.6E-05	1.4E-07	4.7E-06	1.7E-07	5.5E-09
7A	15	842	5.0E+05	1.5E-01	6.0E-01	86000	4400.1	4.3E-03	5.6E-05	9.1E-07	9.0E-06	4.5E-06	2.6E-08	1.5E-05	3.2E-08	1.9E-09
7A	16	842	5.0E+05	1.5E-01	5.9E-01	90400	3999.9	3.9E-03	9.3E-05	7.7E-07	6.0E-06	2.6E-06	1.1E-08	2.5E-05	8.2E-09	1.0E-09
7A	17	842	5.2E+05	1.5E-01	5.9E-01	94400	4000	4.0E-03	7.5E-05	7.3E-07	6.5E-06	2.3E-06	7.8E-09	2.0E-05	4.0E-09	1.0E-09
7A	18	820	3.3E+03	9.8E-04	6.1E-01	98400	24000	1.6E-04	6.5E-07	2.3E-08	3.1E-07	6.4E-08	1.1E-10	1.6E-07	7.1E-11	4.0E-11
7A	19	821	2.7E+03	8.1E-04	6.1E-01	98400	24000	1.3E-04	5.3E-07	1.9E-08	2.5E-07	5.3E-08	8.8E-11	1.3E-07	5.9E-11	3.3E-11
7A	20	824	1.6E+03	4.6E-04	6.1E-01	98400	24000	7.5E-05	3.0E-07	1.1E-08	1.4E-07	3.0E-08	5.0E-11	7.4E-08	3.4E-11	1.9E-11
7A	21	842	5.3E+05	1.6E-01	5.9E-01	98400	4000.1	4.1E-03	3.6E-05	9.8E-07	8.2E-06	2.2E-06	6.1E-09	9.4E-06	3.0E-09	1.2E-09
7A	22	842	5.4E+05	1.6E-01	5.8E-01	102400	3999.9	4.1E-03	2.3E-05	9.7E-07	9.7E-06	2.1E-06	4.3E-09	5.3E-06	2.5E-09	1.3E-09
7A	23	842	5.5E+05	1.6E-01	5.8E-01	106400	4000.1	4.2E-03	1.5E-05	1.0E-06	1.1E-05	2.1E-06	2.9E-09	3.1E-06	2.1E-09	1.4E-09
7A	24	842	5.6E+05	1.7E-01	5.8E-01	110400	4000	4.2E-03	9.2E-06	6.5E-07	1.1E-05	2.1E-06	1.9E-09	1.8E-06	1.9E-09	1.4E-09
7A	25	842	5.7E+05	1.7E-01	5.8E-01	114400	3999.9	4.2E-03	6.2E-06	3.9E-07	1.1E-05	2.1E-06	1.3E-09	1.1E-06	1.7E-09	1.4E-09
7A	26	842	5.7E+05	1.7E-01	5.7E-01	118400	4000.2	4.3E-03	4.6E-06	2.6E-07	1.1E-05	2.2E-06	7.6E-10	6.8E-07	1.6E-09	1.4E-09
7A	27	820	3.3E+03	9.9E-04	5.9E-01	122400	21600	1.4E-04	8.1E-08	3.6E-09	2.2E-07	5.9E-08	9.4E-12	8.0E-09	3.8E-11	3.4E-11
7A	28	821	2.8E+03	8.1E-04	5.9E-01	122400	21600	1.2E-04	6.7E-08	3.0E-09	1.8E-07	4.9E-08	7.8E-12	6.6E-09	3.1E-11	2.8E-11
7A	29	824	1.6E+03	4.6E-04	5.9E-01	122400	21600	6.7E-05	3.8E-08	1.7E-09	1.0E-07	2.8E-08	4.4E-12	3.7E-09	1.8E-11	1.6E-11
7A	30	842	5.8E+05	1.7E-01	5.7E-01	122400	4000	4.3E-03	3.7E-06	1.8E-07	1.1E-05	2.2E-06	5.2E-10	4.3E-07	1.5E-09	1.3E-09
7A	31	842	5.8E+05	1.7E-01	5.7E-01	126400	3999.8	4.3E-03	3.0E-06	1.3E-07	8.2E-06	2.2E-06	4.1E-10	2.9E-07	1.4E-09	1.3E-09
7A	32	842	5.9E+05	1.7E-01	5.7E-01	130400	4000.1	4.3E-03	2.7E-06	1.0E-07	6.7E-06	2.2E-06	2.3E-10	2.0E-07	1.4E-09	1.3E-09
7A	33	842	5.9E+05	1.8E-01	5.7E-01	134400	4000.1	4.3E-03	2.4E-06	8.9E-08	5.9E-06	2.2E-06	1.7E-10	1.5E-07	1.3E-09	1.2E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	34	842	5.9E+05	1.8E-01	5.6E-01	138400	5599.9	6.0E-03	2.7E-06	1.1E-07	7.7E-06	3.1E-06	1.2E-10	1.6E-07	1.8E-09	1.7E-09
7A	35	820	3.3E+03	9.9E-04	5.8E-01	144000	22400	1.5E-04	3.9E-08	2.2E-09	1.5E-07	6.3E-08	1.3E-12	2.4E-09	3.2E-11	3.1E-11
7A	36	821	2.8E+03	8.1E-04	5.8E-01	144000	22400	1.2E-04	3.3E-08	1.8E-09	1.2E-07	5.2E-08	1.1E-12	2.0E-09	2.7E-11	2.6E-11
7A	37	824	1.6E+03	4.6E-04	5.8E-01	144000	22400	6.8E-05	1.9E-08	1.0E-09	7.0E-08	3.0E-08	6.3E-13	1.1E-09	1.5E-11	1.5E-11
7A	38	842	5.9E+05	1.8E-01	5.6E-01	144000	2400.1	2.6E-03	9.9E-07	4.8E-08	3.2E-06	1.4E-06	5.8E-11	6.0E-08	7.4E-10	7.1E-10
7A	39	842	6.0E+05	1.8E-01	5.6E-01	146400	4000	4.3E-03	1.5E-06	7.9E-08	5.2E-06	2.3E-06	5.8E-11	9.1E-08	1.2E-09	1.2E-09
7A	40	842	6.0E+05	1.8E-01	5.6E-01	150400	3999.9	4.3E-03	1.4E-06	8.0E-08	5.1E-06	2.3E-06	0.0E+00	8.5E-08	1.2E-09	1.1E-09
7A	41	842	6.0E+05	1.8E-01	5.6E-01	154400	4000	4.3E-03	1.3E-06	8.1E-08	5.2E-06	2.4E-06	5.8E-11	8.2E-08	1.2E-09	1.1E-09
7A	42	842	6.0E+05	1.8E-01	5.5E-01	158400	4000	4.3E-03	1.3E-06	8.2E-08	5.4E-06	2.4E-06	0.0E+00	8.1E-08	1.1E-09	1.1E-09
7A	43	842	6.1E+05	1.8E-01	5.5E-01	162400	4000.1	4.3E-03	1.2E-06	8.2E-08	5.6E-06	2.3E-06	5.8E-11	7.8E-08	1.1E-09	1.1E-09
7A	44	820	3.4E+03	9.9E-04	5.7E-01	166400	18400	1.2E-04	2.5E-08	1.8E-09	1.3E-07	4.1E-08	2.8E-13	1.7E-09	2.3E-11	2.3E-11
7A	45	821	2.8E+03	8.2E-04	5.7E-01	166400	18400	9.7E-05	2.1E-08	1.5E-09	1.1E-07	3.4E-08	1.7E-13	1.4E-09	1.9E-11	1.9E-11
7A	46	824	1.6E+03	4.7E-04	5.7E-01	166400	18400	5.5E-05	1.2E-08	8.7E-10	6.2E-08	1.9E-08	9.9E-14	8.1E-10	1.1E-11	1.1E-11
7A	47	842	6.1E+05	1.8E-01	5.5E-01	166400	3999.8	4.3E-03	1.1E-06	8.2E-08	5.6E-06	2.0E-06	0.0E+00	7.7E-08	1.1E-09	1.0E-09
7A	48	842	6.1E+05	1.8E-01	5.5E-01	170400	2400.1	2.6E-03	6.7E-07	4.9E-08	3.4E-06	1.2E-06	0.0E+00	4.6E-08	6.2E-10	6.2E-10
7A	49	842	6.1E+05	1.8E-01	5.5E-01	172800	4000	4.3E-03	1.1E-06	8.3E-08	5.8E-06	1.7E-06	0.0E+00	7.7E-08	1.0E-09	1.0E-09
7A	50	842	6.1E+05	1.8E-01	5.5E-01	176800	4000	4.3E-03	1.1E-06	8.2E-08	6.0E-06	1.5E-06	0.0E+00	7.5E-08	9.9E-10	9.9E-10
7A	51	842	1.2E+06	3.5E-01	5.3E-01	180800	4000.1	8.6E-03	2.2E-06	1.8E-07	1.3E-05	2.9E-06	0.0E+00	1.6E-07	2.1E-09	2.1E-09
7A	52	820	3.3E+03	9.8E-04	5.3E-01	184800	24000	1.4E-04	5.7E-08	4.3E-09	3.8E-07	6.3E-08	1.1E-13	4.0E-09	4.8E-11	4.8E-11
7A	53	821	2.7E+03	8.1E-04	5.3E-01	184800	24000	1.1E-04	4.7E-08	3.5E-09	3.1E-07	5.2E-08	1.1E-13	3.3E-09	4.0E-11	4.0E-11
7A	54	824	1.6E+03	4.6E-04	5.3E-01	184800	24000	6.6E-05	2.7E-08	2.0E-09	1.8E-07	3.0E-08	8.5E-14	1.9E-09	2.3E-11	2.3E-11
7A	55	842	3.9E+06	1.1E+00	5.2E-01	184800	4000	2.8E-02	8.1E-06	6.4E-07	5.0E-05	1.0E-05	5.8E-11	5.8E-07	7.4E-09	7.4E-09
7A	56	842	3.1E+06	9.0E-01	5.1E-01	188800	3999.9	2.2E-02	7.5E-06	5.9E-07	4.8E-05	8.9E-06	0.0E+00	5.5E-07	6.8E-09	6.8E-09
7A	57	842	3.1E+06	8.9E-01	5.0E-01	192800	4000.1	2.1E-02	8.7E-06	6.7E-07	5.7E-05	9.7E-06	5.8E-11	6.2E-07	7.5E-09	7.5E-09
7A	58	842	3.0E+06	8.9E-01	5.0E-01	196800	3999.8	2.1E-02	9.8E-06	7.3E-07	6.5E-05	1.0E-05	0.0E+00	6.9E-07	8.1E-09	8.1E-09
7A	59	842	3.0E+06	8.8E-01	4.9E-01	200800	4000	2.0E-02	1.1E-05	7.8E-07	7.4E-05	1.1E-05	5.8E-11	7.5E-07	8.6E-09	8.6E-09
7A	60	842	3.0E+06	8.8E-01	4.9E-01	204800	4000.2	2.0E-02	1.2E-05	8.3E-07	8.4E-05	1.2E-05	0.0E+00	8.1E-07	9.0E-09	9.1E-09
7A	61	820	3.2E+03	9.5E-04	5.1E-01	208800	20000	1.0E-04	8.0E-08	5.0E-09	5.9E-07	7.3E-08	1.1E-13	4.9E-09	5.2E-11	5.3E-11
7A	62	821	2.6E+03	7.8E-04	5.1E-01	208800	20000	8.3E-05	6.6E-08	4.1E-09	4.9E-07	6.0E-08	1.1E-13	4.1E-09	4.3E-11	4.4E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	63	842	3.0E+06	8.7E-01	4.9E-01	208800	3999.8	1.9E-02	1.3E-05	8.7E-07	9.4E-05	1.3E-05	0.0E+00	8.5E-07	9.3E-09	9.4E-09
7A	64	842	3.0E+06	8.7E-01	4.8E-01	212800	4000.2	1.9E-02	1.4E-05	9.1E-07	1.0E-04	1.3E-05	0.0E+00	9.0E-07	9.6E-09	9.7E-09
7A	65	842	2.9E+06	8.6E-01	4.8E-01	216800	4000	1.8E-02	1.5E-05	9.4E-07	1.1E-04	1.4E-05	5.8E-11	9.4E-07	9.8E-09	1.0E-08
7A	66	842	2.9E+06	8.6E-01	4.7E-01	220800	3999.8	1.8E-02	1.6E-05	9.7E-07	1.2E-04	1.4E-05	0.0E+00	9.7E-07	1.0E-08	1.0E-08
7A	67	842	2.9E+06	8.6E-01	4.7E-01	224800	4000.1	1.7E-02	1.7E-05	9.9E-07	1.3E-04	1.5E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	68	820	3.1E+03	9.3E-04	4.9E-01	228800	24000	1.0E-04	1.3E-07	6.8E-09	1.0E-06	1.1E-07	5.7E-14	6.7E-09	6.6E-11	6.8E-11
7A	69	821	2.6E+03	7.7E-04	4.9E-01	228800	24000	8.6E-05	1.0E-07	5.6E-09	8.5E-07	9.1E-08	5.7E-14	5.6E-09	5.5E-11	5.6E-11
7A	70	824	1.5E+03	4.4E-04	4.9E-01	228800	24000	4.9E-05	6.0E-08	3.2E-09	4.9E-07	5.2E-08	4.3E-14	3.2E-09	3.1E-11	3.2E-11
7A	71	842	2.9E+06	8.5E-01	4.7E-01	228800	4000	1.7E-02	1.8E-05	1.0E-06	1.4E-04	1.6E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	72	842	2.9E+06	8.5E-01	4.7E-01	232800	4000.1	1.6E-02	1.9E-05	1.0E-06	1.5E-04	1.6E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	73	842	2.9E+06	8.5E-01	4.6E-01	236800	4000	1.6E-02	2.0E-05	1.0E-06	1.6E-04	1.7E-05	5.8E-11	1.0E-06	1.0E-08	1.0E-08
7A	74	842	2.8E+06	8.5E-01	4.6E-01	240800	4000	1.5E-02	2.0E-05	1.1E-06	1.7E-04	1.8E-05	0.0E+00	1.1E-06	1.0E-08	1.0E-08
7A	75	842	2.8E+06	8.5E-01	4.6E-01	244800	4000	1.5E-02	2.1E-05	1.1E-06	1.8E-04	1.8E-05	0.0E+00	1.1E-06	1.0E-08	1.0E-08
7A	76	842	2.8E+06	8.4E-01	4.6E-01	248800	4000	1.5E-02	2.0E-05	1.1E-06	1.7E-04	1.9E-05	5.8E-11	1.1E-06	1.0E-08	1.0E-08
7A	77	820	3.0E+03	9.3E-04	4.7E-01	252800	20000	7.4E-05	9.9E-08	6.2E-09	7.3E-07	1.2E-07	5.7E-14	5.7E-09	5.5E-11	5.6E-11
7A	78	821	2.5E+03	7.7E-04	4.7E-01	252800	20000	6.1E-05	8.2E-08	5.1E-09	6.0E-07	9.8E-08	0.0E+00	4.7E-09	4.5E-11	4.6E-11
7A	79	842	2.8E+06	8.4E-01	4.5E-01	252800	3999.9	1.4E-02	2.0E-05	1.1E-06	1.5E-04	2.0E-05	0.0E+00	1.1E-06	1.0E-08	1.0E-08
7A	80	842	2.8E+06	8.4E-01	4.5E-01	256800	4000.1	1.4E-02	1.9E-05	1.1E-06	1.4E-04	2.1E-05	0.0E+00	1.1E-06	1.0E-08	1.0E-08
7A	81	842	2.8E+06	8.4E-01	4.5E-01	260800	4000	1.3E-02	1.8E-05	1.2E-06	1.3E-04	2.2E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	82	842	2.8E+06	8.4E-01	4.5E-01	264800	3999.9	1.3E-02	1.7E-05	1.2E-06	1.2E-04	2.4E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	83	842	2.8E+06	8.4E-01	4.5E-01	268800	4000.1	1.3E-02	1.7E-05	1.3E-06	1.1E-04	2.5E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	84	820	3.0E+03	9.3E-04	4.6E-01	272800	20000	6.4E-05	8.2E-08	8.6E-09	5.1E-07	1.8E-07	0.0E+00	6.6E-09	5.5E-11	5.7E-11
7A	85	821	2.5E+03	7.7E-04	4.6E-01	272800	20000	5.3E-05	6.7E-08	7.1E-09	4.2E-07	1.5E-07	5.7E-14	5.4E-09	4.6E-11	4.7E-11
7A	86	842	2.8E+06	8.4E-01	4.4E-01	272800	3999.9	1.2E-02	1.6E-05	1.3E-06	1.0E-04	2.7E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	87	842	2.8E+06	8.4E-01	4.4E-01	276800	4000	1.2E-02	1.5E-05	1.5E-06	9.7E-05	3.0E-05	0.0E+00	1.0E-06	1.0E-08	1.0E-08
7A	88	842	2.8E+06	8.4E-01	4.4E-01	280800	3999.9	1.1E-02	1.5E-05	1.6E-06	9.1E-05	3.4E-05	0.0E+00	1.1E-06	1.0E-08	1.1E-08
7A	89	842	2.8E+06	8.4E-01	4.4E-01	284800	4000.1	1.1E-02	1.4E-05	1.8E-06	8.5E-05	3.9E-05	0.0E+00	1.3E-06	1.0E-08	1.1E-08
7A	90	842	2.8E+06	8.4E-01	4.4E-01	288800	4000.1	1.1E-02	1.4E-05	2.0E-06	8.0E-05	4.7E-05	0.0E+00	2.1E-06	1.1E-08	1.1E-08
7A	91	820	3.0E+03	9.5E-04	4.6E-01	292800	24000	6.5E-05	7.6E-08	1.3E-08	3.0E-07	3.1E-07	1.5E-12	4.9E-05	5.1E-11	5.2E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	92	821	2.5E+03	7.8E-04	4.6E-01	292800	24000	5.4E-05	6.3E-08	1.1E-08	2.5E-07	2.6E-07	1.3E-12	4.0E-05	4.2E-11	4.3E-11
7A	93	824	1.4E+03	4.5E-04	4.6E-01	292800	24000	3.1E-05	3.6E-08	6.3E-09	1.4E-07	1.5E-07	7.0E-13	2.3E-05	2.4E-11	2.5E-11
7A	94	842	2.8E+06	8.5E-01	4.4E-01	292800	4000.1	1.0E-02	1.3E-05	2.2E-06	7.5E-05	6.4E-05	5.8E-11	2.1E-03	1.1E-08	1.1E-08
7A	95	842	2.8E+06	8.5E-01	4.4E-01	296800	3999.7	1.0E-02	1.2E-05	2.3E-06	6.1E-05	8.7E-05	1.2E-10	2.2E-02	9.8E-09	1.0E-08
7A	96	842	2.8E+06	8.5E-01	4.4E-01	300800	4000.2	9.8E-03	1.1E-05	2.2E-06	4.4E-05	5.7E-05	2.3E-10	1.1E-02	7.9E-09	8.1E-09
7A	97	842	2.8E+06	8.6E-01	4.4E-01	304800	4000.1	9.5E-03	1.1E-05	2.1E-06	3.4E-05	3.8E-05	5.2E-10	6.8E-03	6.8E-09	7.0E-09
7A	98	842	2.8E+06	8.6E-01	4.4E-01	308800	3999.8	9.2E-03	1.2E-05	2.2E-06	3.0E-05	2.7E-05	3.5E-10	4.8E-03	6.6E-09	6.7E-09
7A	99	842	2.8E+06	8.7E-01	4.4E-01	312800	4000	8.9E-03	1.4E-05	2.2E-06	2.8E-05	2.0E-05	4.1E-10	3.5E-03	6.4E-09	6.6E-09
7A	100	820	3.1E+03	9.9E-04	4.5E-01	316800	20000	4.6E-05	1.0E-07	1.4E-08	1.8E-07	6.5E-08	2.8E-12	1.1E-05	3.9E-11	3.9E-11
7A	101	821	2.6E+03	8.2E-04	4.5E-01	316800	20000	3.8E-05	8.3E-08	1.2E-08	1.5E-07	5.4E-08	2.3E-12	9.2E-06	3.2E-11	3.2E-11
7A	102	824	1.5E+03	4.7E-04	4.6E-01	316800	20000	2.2E-05	4.8E-08	6.6E-09	8.7E-08	3.1E-08	1.3E-12	5.2E-06	1.8E-11	1.8E-11
7A	103	842	2.8E+06	8.7E-01	4.4E-01	316800	3999.9	8.6E-03	1.6E-05	2.3E-06	3.1E-05	1.6E-05	4.7E-10	2.8E-03	6.6E-09	6.7E-09
7A	104	842	2.8E+06	8.8E-01	4.4E-01	320800	4000.3	8.3E-03	1.8E-05	2.5E-06	3.4E-05	1.3E-05	5.2E-10	2.2E-03	6.8E-09	7.0E-09
7A	105	842	2.8E+06	8.8E-01	4.4E-01	324800	3999.9	8.1E-03	2.0E-05	2.6E-06	3.6E-05	1.1E-05	5.2E-10	1.8E-03	7.1E-09	7.2E-09
7A	106	842	2.8E+06	8.9E-01	4.4E-01	328800	3999.9	7.8E-03	2.1E-05	2.9E-06	3.5E-05	9.1E-06	5.8E-10	1.5E-03	7.8E-09	7.9E-09
7A	107	842	2.8E+06	8.9E-01	4.4E-01	332800	4000.1	7.6E-03	2.3E-05	3.2E-06	4.1E-05	8.0E-06	7.0E-10	1.3E-03	8.4E-09	8.5E-09
7A	108	820	3.2E+03	1.0E-03	4.5E-01	336800	24000	4.7E-05	1.8E-07	2.6E-08	2.9E-07	3.8E-08	5.6E-12	5.8E-06	6.5E-11	6.6E-11
7A	109	821	2.6E+03	8.5E-04	4.5E-01	336800	24000	3.8E-05	1.5E-07	2.1E-08	2.4E-07	3.1E-08	4.7E-12	4.8E-06	5.4E-11	5.5E-11
7A	110	842	2.8E+06	9.0E-01	4.4E-01	336800	4000	7.3E-03	2.5E-05	3.5E-06	4.4E-05	7.0E-06	7.0E-10	1.1E-03	8.9E-09	9.0E-09
7A	111	842	2.9E+06	9.1E-01	4.4E-01	340800	3999.9	7.1E-03	2.6E-05	3.7E-06	4.2E-05	6.2E-06	8.7E-10	9.8E-04	9.5E-09	9.6E-09
7A	112	842	2.9E+06	9.1E-01	4.4E-01	344800	4000.1	6.9E-03	2.8E-05	4.0E-06	4.4E-05	5.6E-06	8.1E-10	8.6E-04	1.0E-08	1.0E-08
7A	113	842	2.9E+06	9.2E-01	4.4E-01	348800	3999.9	6.7E-03	2.9E-05	4.1E-06	4.4E-05	5.1E-06	8.7E-10	7.6E-04	1.0E-08	1.0E-08
7A	114	842	2.9E+06	9.2E-01	4.4E-01	352800	4000	6.4E-03	3.0E-05	4.3E-06	4.6E-05	4.7E-06	9.3E-10	6.8E-04	1.1E-08	1.1E-08
7A	115	842	2.9E+06	9.3E-01	4.4E-01	356800	4000	6.2E-03	3.1E-05	4.5E-06	4.8E-05	4.3E-06	1.0E-09	6.0E-04	1.1E-08	1.1E-08
7A	116	842	2.9E+06	9.3E-01	4.4E-01	360800	3999.9	6.0E-03	3.2E-05	4.7E-06	4.7E-05	4.0E-06	9.3E-10	5.4E-04	1.2E-08	1.2E-08
7A	117	842	2.9E+06	9.4E-01	4.4E-01	364800	4000.1	5.9E-03	3.2E-05	4.8E-06	4.6E-05	3.7E-06	1.1E-09	4.9E-04	1.2E-08	1.2E-08
7A	118	842	2.9E+06	9.5E-01	4.4E-01	368800	3999.9	5.7E-03	3.3E-05	5.0E-06	5.0E-05	3.5E-06	1.0E-09	4.4E-04	1.2E-08	1.2E-08
7A	119	842	3.0E+06	9.5E-01	4.4E-01	372800	4000.2	5.5E-03	3.4E-05	5.1E-06	6.3E-05	3.4E-06	1.1E-09	4.0E-04	1.3E-08	1.3E-08
7A	120	842	3.0E+06	9.6E-01	4.4E-01	376800	3999.9	5.3E-03	3.4E-05	5.3E-06	6.3E-05	3.2E-06	1.2E-09	3.6E-04	1.3E-08	1.3E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	121	842	3.0E+06	9.6E-01	4.4E-01	380800	4000.1	5.2E-03	3.4E-05	5.4E-06	6.0E-05	3.0E-06	1.1E-09	3.3E-04	1.3E-08	1.3E-08
7A	122	842	3.0E+06	9.7E-01	4.4E-01	384800	3999.9	5.0E-03	3.4E-05	5.4E-06	5.8E-05	2.8E-06	1.2E-09	3.0E-04	1.3E-08	1.3E-08
7A	123	842	3.0E+06	9.8E-01	4.4E-01	388800	4000.2	4.9E-03	3.4E-05	5.5E-06	5.6E-05	2.6E-06	1.2E-09	2.7E-04	1.3E-08	1.3E-08
7A	124	842	3.0E+06	9.8E-01	4.4E-01	392800	3999.9	4.7E-03	3.3E-05	5.6E-06	5.3E-05	2.5E-06	1.2E-09	2.5E-04	1.3E-08	1.3E-08
7A	125	842	3.0E+06	9.8E-01	4.4E-01	396800	4000	4.6E-03	3.3E-05	5.5E-06	5.1E-05	2.3E-06	1.2E-09	2.2E-04	1.3E-08	1.3E-08
7A	126	820	3.5E+03	1.2E-03	4.5E-01	400800	24000	2.8E-05	2.1E-07	3.8E-08	3.0E-07	1.3E-08	7.7E-12	1.2E-06	9.1E-11	9.2E-11
7A	127	821	2.9E+03	9.5E-04	4.5E-01	400800	24000	2.3E-05	1.7E-07	3.2E-08	2.4E-07	1.1E-08	6.4E-12	9.5E-07	7.5E-11	7.6E-11
7A	128	842	3.0E+06	9.9E-01	4.4E-01	400800	4000	4.4E-03	3.2E-05	5.6E-06	4.9E-05	2.2E-06	1.1E-09	2.0E-04	1.3E-08	1.4E-08
7A	129	842	3.0E+06	9.9E-01	4.4E-01	404800	3999.9	4.3E-03	3.2E-05	5.6E-06	4.6E-05	2.0E-06	1.2E-09	1.9E-04	1.3E-08	1.4E-08
7A	130	842	3.1E+06	1.0E+00	4.4E-01	408800	4000	4.1E-03	3.1E-05	5.7E-06	4.3E-05	1.9E-06	1.1E-09	1.7E-04	1.4E-08	1.4E-08
7A	131	842	3.1E+06	1.0E+00	4.4E-01	412800	4000	4.0E-03	3.0E-05	5.7E-06	4.1E-05	1.8E-06	1.2E-09	1.6E-04	1.4E-08	1.4E-08
7A	132	842	3.1E+06	1.0E+00	4.4E-01	416800	4000	3.9E-03	2.9E-05	5.7E-06	3.9E-05	1.6E-06	1.2E-09	1.4E-04	1.3E-08	1.4E-08
7A	133	842	3.1E+06	1.0E+00	4.4E-01	420800	3999.9	3.8E-03	2.9E-05	5.6E-06	3.8E-05	1.5E-06	1.0E-09	1.3E-04	1.3E-08	1.3E-08
7A	134	842	3.1E+06	1.0E+00	4.4E-01	424800	4000.1	3.6E-03	2.8E-05	5.6E-06	3.7E-05	1.5E-06	1.1E-09	1.2E-04	1.3E-08	1.3E-08
7A	135	842	3.1E+06	1.0E+00	4.4E-01	428800	4000	3.5E-03	2.7E-05	5.5E-06	3.5E-05	1.4E-06	1.0E-09	1.1E-04	1.3E-08	1.3E-08
7A	136	842	3.1E+06	1.0E+00	4.3E-01	432800	4000.2	3.4E-03	2.6E-05	5.5E-06	3.4E-05	1.3E-06	1.0E-09	9.8E-05	1.3E-08	1.3E-08
7A	137	842	3.1E+06	1.0E+00	4.3E-01	436800	3999.9	3.3E-03	2.6E-05	5.4E-06	3.2E-05	1.7E-06	1.5E-08	9.6E-05	1.3E-08	1.3E-08
7A	138	842	3.0E+06	9.9E-01	4.3E-01	440800	3999.8	3.2E-03	2.5E-05	5.2E-06	3.1E-05	2.7E-06	5.7E-08	1.1E-04	1.4E-08	1.3E-08
7A	139	820	3.1E+03	1.0E-03	4.4E-01	444800	24000	2.0E-05	1.6E-07	3.3E-08	1.9E-07	1.3E-08	2.5E-10	5.1E-07	8.6E-11	8.0E-11
7A	140	842	2.9E+06	9.6E-01	4.3E-01	444800	4000.1	3.1E-03	2.4E-05	5.2E-06	3.0E-05	2.3E-06	4.6E-08	9.4E-05	1.4E-08	1.2E-08
7A	141	842	2.9E+06	9.4E-01	4.3E-01	448800	4000.1	3.0E-03	2.4E-05	4.9E-06	3.0E-05	2.2E-06	4.2E-08	8.4E-05	1.3E-08	1.2E-08
7A	142	842	2.8E+06	9.1E-01	4.3E-01	452800	3999.9	2.9E-03	2.3E-05	4.9E-06	2.9E-05	2.0E-06	3.7E-08	7.6E-05	1.3E-08	1.2E-08
7A	143	842	2.7E+06	8.9E-01	4.2E-01	456800	4000.1	2.9E-03	2.3E-05	4.9E-06	2.8E-05	1.9E-06	3.4E-08	6.9E-05	1.3E-08	1.2E-08
7A	144	842	2.7E+06	8.7E-01	4.2E-01	460800	4000	2.8E-03	2.3E-05	4.8E-06	2.7E-05	1.7E-06	3.0E-08	6.2E-05	1.3E-08	1.2E-08
7A	145	842	2.6E+06	8.4E-01	4.2E-01	464800	3999.8	2.7E-03	2.3E-05	4.8E-06	2.6E-05	1.7E-06	2.7E-08	5.6E-05	1.2E-08	1.2E-08
7A	146	842	2.5E+06	8.2E-01	4.2E-01	468800	4000.2	2.6E-03	2.4E-05	4.7E-06	2.5E-05	1.6E-06	2.5E-08	5.1E-05	1.2E-08	1.2E-08
7A	147	842	2.5E+06	8.0E-01	4.2E-01	472800	4000	2.5E-03	2.4E-05	4.6E-06	2.5E-05	1.5E-06	2.2E-08	4.6E-05	1.2E-08	1.2E-08
7A	148	842	2.4E+06	7.8E-01	4.2E-01	476800	3999.9	2.4E-03	2.5E-05	4.6E-06	2.5E-05	1.5E-06	2.0E-08	4.2E-05	1.2E-08	1.2E-08
7A	149	842	2.4E+06	7.6E-01	4.2E-01	480800	4000	2.4E-03	2.7E-05	4.4E-06	2.6E-05	1.5E-06	1.8E-08	3.9E-05	1.2E-08	1.1E-08

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	150	842	2.3E+06	7.4E-01	4.2E-01	484800	4000.1	2.3E-03	2.8E-05	4.2E-06	2.6E-05	1.5E-06	1.6E-08	3.5E-05	1.2E-08	1.1E-08
7A	151	842	2.2E+06	7.2E-01	4.2E-01	488800	3999.8	2.2E-03	2.9E-05	4.2E-06	2.6E-05	1.5E-06	1.4E-08	3.3E-05	1.2E-08	1.1E-08
7A	152	842	2.2E+06	7.0E-01	4.1E-01	492800	4000.1	2.2E-03	3.1E-05	4.0E-06	2.7E-05	1.5E-06	1.3E-08	3.0E-05	1.1E-08	1.1E-08
7A	153	842	2.1E+06	6.9E-01	4.1E-01	496800	4000	2.1E-03	3.3E-05	4.0E-06	2.7E-05	1.6E-06	1.1E-08	2.8E-05	1.1E-08	1.1E-08
7A	154	842	2.1E+06	6.7E-01	4.1E-01	500800	3999.9	2.0E-03	3.5E-05	4.0E-06	2.8E-05	1.7E-06	1.0E-08	2.7E-05	1.1E-08	1.1E-08
7A	155	842	2.0E+06	6.5E-01	4.1E-01	504800	4000	2.0E-03	3.8E-05	3.8E-06	3.1E-05	1.9E-06	9.2E-09	2.5E-05	1.1E-08	1.1E-08
7A	156	842	2.0E+06	6.4E-01	4.1E-01	508800	4000.2	1.9E-03	4.1E-05	3.8E-06	3.1E-05	2.0E-06	8.1E-09	2.4E-05	1.1E-08	1.1E-08
7A	157	842	1.9E+06	6.2E-01	4.1E-01	512800	4000	1.8E-03	4.4E-05	3.7E-06	3.1E-05	2.2E-06	7.4E-09	2.3E-05	1.1E-08	1.1E-08
7A	158	842	1.9E+06	6.0E-01	4.1E-01	516800	3999.8	1.8E-03	4.7E-05	3.7E-06	3.2E-05	2.5E-06	6.7E-09	2.3E-05	1.1E-08	1.1E-08
7A	159	842	1.9E+06	5.9E-01	4.1E-01	520800	4000.1	1.7E-03	5.1E-05	3.6E-06	3.7E-05	2.8E-06	5.9E-09	2.2E-05	1.1E-08	1.1E-08
7A	160	842	1.8E+06	5.7E-01	4.0E-01	524800	3999.9	1.7E-03	5.5E-05	3.4E-06	4.6E-05	3.2E-06	5.4E-09	2.2E-05	1.1E-08	1.1E-08
7A	161	842	1.8E+06	5.6E-01	4.0E-01	528800	4000.1	1.6E-03	5.9E-05	3.4E-06	5.2E-05	3.7E-06	4.7E-09	2.2E-05	1.1E-08	1.1E-08
7A	162	842	1.7E+06	5.5E-01	4.0E-01	532800	4000	1.6E-03	6.4E-05	3.3E-06	5.9E-05	4.3E-06	4.4E-09	2.3E-05	1.1E-08	1.1E-08
7A	163	842	1.7E+06	5.3E-01	4.0E-01	536800	4000	1.5E-03	6.9E-05	3.2E-06	7.8E-05	5.2E-06	3.8E-09	2.3E-05	1.1E-08	1.1E-08
7A	164	842	1.6E+06	5.2E-01	4.0E-01	540800	4000	1.5E-03	7.6E-05	3.1E-06	1.0E-04	6.2E-06	3.5E-09	2.3E-05	1.1E-08	1.1E-08
7A	165	842	1.6E+06	5.1E-01	4.0E-01	544800	4000.1	1.4E-03	8.3E-05	3.1E-06	1.4E-04	7.4E-06	3.1E-09	2.4E-05	1.1E-08	1.1E-08
7A	166	842	1.6E+06	5.0E-01	4.0E-01	548800	3999.9	1.4E-03	8.8E-05	2.9E-06	1.5E-04	8.8E-06	2.8E-09	2.5E-05	1.1E-08	1.1E-08
7A	167	842	1.5E+06	4.8E-01	4.0E-01	552800	4000	1.3E-03	9.2E-05	2.9E-06	1.3E-04	1.0E-05	2.6E-09	2.6E-05	1.1E-08	1.1E-08
7A	168	842	1.5E+06	4.7E-01	4.0E-01	556800	4000	1.3E-03	9.5E-05	2.8E-06	1.2E-04	1.2E-05	2.4E-09	2.7E-05	1.1E-08	1.1E-08
7A	169	842	1.5E+06	4.6E-01	4.0E-01	560800	4000	1.3E-03	1.0E-04	3.5E-06	1.1E-04	1.5E-05	2.0E-09	2.8E-05	1.1E-08	1.1E-08
7A	170	842	1.4E+06	4.5E-01	3.9E-01	564800	4000	1.2E-03	1.0E-04	4.9E-06	9.9E-05	1.7E-05	1.9E-09	2.9E-05	1.1E-08	1.1E-08
7A	171	842	1.4E+06	4.4E-01	3.9E-01	568800	3906.8	1.1E-03	1.1E-04	6.9E-06	8.9E-05	2.0E-05	1.6E-09	2.9E-05	9.7E-09	9.9E-09
7A	172	842	1.4E+06	4.3E-01	3.9E-01	572710	4293.3	1.2E-03	1.2E-04	1.0E-05	9.0E-05	2.7E-05	1.5E-09	3.4E-05	1.0E-08	1.1E-08
7A	173	842	1.3E+06	4.2E-01	3.9E-01	577000	4000	1.1E-03	1.2E-04	9.9E-06	7.7E-05	2.9E-05	1.4E-09	3.3E-05	9.9E-09	1.0E-08
7A	174	842	1.3E+06	4.1E-01	3.9E-01	581000	4000	1.1E-03	1.2E-04	8.7E-06	7.2E-05	3.4E-05	1.3E-09	3.4E-05	1.0E-08	1.0E-08
7A	175	842	1.3E+06	4.0E-01	3.9E-01	585000	4000	1.0E-03	1.3E-04	7.7E-06	6.8E-05	3.9E-05	1.2E-09	3.4E-05	1.0E-08	1.1E-08
7A	176	842	1.2E+06	3.9E-01	3.9E-01	589000	4000	1.0E-03	1.3E-04	6.7E-06	6.4E-05	4.6E-05	1.1E-09	3.5E-05	1.0E-08	1.1E-08
7A	177	842	1.2E+06	3.8E-01	3.8E-01	593000	3999.9	9.7E-04	1.3E-04	5.8E-06	6.1E-05	5.5E-05	1.0E-09	3.6E-05	9.8E-09	1.0E-08
7A	178	842	1.2E+06	3.7E-01	3.8E-01	597000	4000.1	9.4E-04	1.4E-04	5.0E-06	5.9E-05	6.6E-05	8.1E-10	3.7E-05	9.4E-09	9.7E-09

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
7A	179	842	1.2E+06	3.6E-01	3.8E-01	601000	3800	8.6E-04	1.3E-04	4.1E-06	5.5E-05	7.2E-05	7.0E-10	3.6E-05	8.5E-09	8.9E-09
8	1	379	2.0E+06	6.3E-01	3.3E-01	175900	4000	1.4E-04	4.9E-05	1.1E-05	5.2E-05	5.4E-05	8.7E-09	7.5E-07	1.4E-13	1.4E-13
8	2	377	3.2E+06	9.7E-01	3.2E-01	179900	4000	5.5E-02	5.6E-03	9.5E-05	5.0E-03	4.6E-03	5.8E-06	1.4E-03	4.5E-10	4.5E-10
8	3	379	1.9E+06	5.7E-01	2.9E-01	179900	4000	2.0E-02	2.2E-03	5.9E-05	2.0E-03	1.8E-03	2.2E-06	5.1E-04	1.6E-10	1.6E-10
8	4	377	5.0E+06	1.4E+00	2.3E-01	183900	731.91	4.8E-02	2.1E-03	6.7E-06	2.6E-03	2.2E-03	1.1E-05	5.2E-04	3.5E-10	3.5E-10
8	5	379	1.3E+06	4.3E-01	3.5E-01	183900	4000	1.8E-02	7.4E-04	2.4E-06	9.6E-04	7.9E-04	4.2E-06	1.9E-04	1.3E-10	1.3E-10
8	6	820	3.7E+03	1.0E-03	6.9E-01	184630	22362	1.1E-04	1.4E-05	1.3E-07	1.8E-05	1.8E-05	4.0E-07	3.5E-06	9.4E-12	9.4E-12
8	7	821	3.0E+03	8.5E-04	6.9E-01	184630	22362	8.7E-05	1.1E-05	1.1E-07	1.5E-05	1.5E-05	3.3E-07	2.9E-06	7.8E-12	7.8E-12
8	8	824	1.7E+03	4.8E-04	6.9E-01	184630	22362	5.0E-05	6.5E-06	6.3E-08	8.6E-06	8.3E-06	1.9E-07	1.7E-06	4.4E-12	4.4E-12
8	9	820	4.4E+03	1.2E-03	6.3E-01	206990	20908	1.4E-04	5.1E-06	4.4E-07	7.9E-06	6.8E-06	1.0E-07	1.0E-06	2.2E-08	4.8E-10
8	10	821	3.6E+03	1.0E-03	6.3E-01	206990	20908	1.1E-04	4.2E-06	3.7E-07	6.5E-06	5.6E-06	8.6E-08	8.3E-07	1.8E-08	4.0E-10
8	11	824	2.1E+03	5.8E-04	6.3E-01	206990	20908	6.6E-05	2.4E-06	2.1E-07	3.7E-06	3.2E-06	4.9E-08	4.8E-07	1.0E-08	2.3E-10
8	12	820	4.9E+03	1.4E-03	6.0E-01	227900	20000	1.4E-04	1.8E-06	6.1E-08	1.6E-06	1.6E-06	1.2E-08	4.3E-07	2.7E-09	1.0E-10
8	13	821	4.0E+03	1.1E-03	6.0E-01	227900	20000	1.2E-04	1.5E-06	5.1E-08	1.3E-06	1.3E-06	9.6E-09	3.6E-07	2.2E-09	8.6E-11
8	14	824	2.3E+03	6.5E-04	6.0E-01	227900	20000	6.6E-05	8.5E-07	2.9E-08	7.4E-07	7.4E-07	5.5E-09	2.0E-07	1.3E-09	4.9E-11
8	15	820	5.5E+03	1.6E-03	5.7E-01	247900	24000	1.8E-04	2.3E-06	4.6E-08	1.0E-06	7.8E-07	4.4E-09	6.0E-07	1.1E-09	9.1E-11
8	16	821	4.5E+03	1.3E-03	5.7E-01	247900	24000	1.5E-04	1.9E-06	3.8E-08	8.6E-07	6.4E-07	3.6E-09	5.0E-07	8.8E-10	7.5E-11
8	17	824	2.6E+03	7.4E-04	5.7E-01	247900	24000	8.3E-05	1.1E-06	2.2E-08	4.9E-07	3.7E-07	2.1E-09	2.8E-07	5.0E-10	4.3E-11
8	18	379	1.1E+05	4.0E-02	4.9E-01	251900	4000	0.0E+00	4.6E-06	0.0E+00	1.1E-05	2.1E-08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
8	19	379	1.1E+05	3.9E-02	4.6E-01	255900	4000	0.0E+00	9.4E-06	0.0E+00	2.4E-05	4.5E-08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
8	20	379	1.1E+05	3.9E-02	4.4E-01	259900	4000	0.0E+00	1.2E-05	0.0E+00	3.1E-05	6.2E-08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
8	21	379	1.1E+05	3.9E-02	4.4E-01	263900	3999.9	0.0E+00	7.9E-06	0.0E+00	3.9E-05	8.4E-08	0.0E+00	0.0E+00	2.5E-16	2.8E-17
8	22	379	1.1E+05	3.8E-02	4.2E-01	267900	3999.9	3.5E-07	4.2E-06	1.5E-11	3.3E-05	6.6E-08	4.5E-13	4.1E-10	1.5E-13	2.6E-14
8	23	379	1.1E+05	3.8E-02	4.0E-01	271900	4000.1	7.1E-06	2.7E-06	1.7E-10	1.8E-05	3.4E-08	6.4E-12	4.2E-09	1.8E-12	3.3E-13
8	24	820	6.1E+03	1.8E-03	5.5E-01	271900	20000	1.5E-04	1.2E-06	3.8E-08	6.3E-07	4.0E-07	1.6E-09	3.2E-07	4.3E-10	6.9E-11
8	25	821	5.0E+03	1.5E-03	5.5E-01	271900	20000	1.3E-04	1.0E-06	3.1E-08	5.2E-07	3.3E-07	1.3E-09	2.6E-07	3.5E-10	5.7E-11
8	26	824	2.9E+03	8.3E-04	5.5E-01	271900	20000	7.2E-05	5.8E-07	1.8E-08	3.0E-07	1.9E-07	7.5E-10	1.5E-07	2.0E-10	3.3E-11
8	27	379	1.2E+05	3.8E-02	4.0E-01	275900	4000	3.3E-05	2.3E-06	5.6E-10	1.2E-05	2.4E-08	1.9E-11	9.7E-09	5.2E-12	1.0E-12
8	28	379	1.2E+05	3.8E-02	3.9E-01	279900	3999.9	7.1E-05	3.0E-06	1.1E-09	1.3E-05	3.1E-08	3.2E-11	1.4E-08	9.1E-12	1.9E-12

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8	29	379	1.2E+05	3.9E-02	3.8E-01	283900	4000	1.1E-04	4.2E-06	1.9E-09	1.8E-05	4.7E-08	5.0E-11	1.8E-08	1.5E-11	3.4E-12
8	30	379	1.3E+05	3.9E-02	3.7E-01	287900	4000.1	1.5E-04	5.2E-06	2.7E-09	2.2E-05	6.3E-08	6.5E-11	2.1E-08	1.9E-11	4.9E-12
8	31	379	1.3E+05	3.9E-02	3.7E-01	291900	4000.1	1.9E-04	5.9E-06	3.4E-09	2.5E-05	7.5E-08	7.4E-11	2.2E-08	2.3E-11	6.1E-12
8	32	820	6.6E+03	1.9E-03	5.3E-01	291900	24000	1.9E-04	8.3E-07	4.2E-08	6.3E-07	3.9E-07	9.8E-10	2.1E-07	3.0E-10	7.7E-11
8	33	821	5.5E+03	1.6E-03	5.3E-01	291900	24000	1.5E-04	6.8E-07	3.4E-08	5.2E-07	3.2E-07	8.1E-10	1.7E-07	2.4E-10	6.4E-11
8	34	824	3.1E+03	9.1E-04	5.3E-01	291900	24000	8.8E-05	3.9E-07	2.0E-08	2.9E-07	1.8E-07	4.6E-10	9.7E-08	1.4E-10	3.6E-11
8	35	379	1.3E+05	3.9E-02	3.6E-01	295900	3999.9	2.3E-04	6.4E-06	4.0E-09	2.7E-05	8.5E-08	7.9E-11	2.1E-08	2.5E-11	7.3E-12
8	36	379	1.4E+05	4.0E-02	3.6E-01	299900	4000	2.6E-04	6.9E-06	4.5E-09	2.8E-05	9.4E-08	8.1E-11	2.1E-08	2.7E-11	8.3E-12
8	37	379	1.4E+05	4.0E-02	3.5E-01	303900	3999.9	2.9E-04	7.2E-06	4.9E-09	2.9E-05	1.0E-07	8.3E-11	2.0E-08	2.8E-11	9.3E-12
8	38	379	1.4E+05	4.0E-02	3.5E-01	307900	4000.2	3.2E-04	7.5E-06	5.3E-09	3.0E-05	1.1E-07	8.4E-11	1.9E-08	2.9E-11	1.0E-11
8	39	379	1.4E+05	4.1E-02	3.5E-01	311900	3999.9	3.4E-04	7.6E-06	5.7E-09	3.0E-05	1.1E-07	8.3E-11	1.9E-08	3.0E-11	1.1E-11
8	40	379	1.5E+05	4.1E-02	3.5E-01	315900	3999.9	3.6E-04	7.2E-06	5.8E-09	2.9E-05	1.1E-07	7.9E-11	1.8E-08	2.9E-11	1.2E-11
8	41	820	7.2E+03	2.1E-03	5.2E-01	315900	20000	1.6E-04	4.1E-07	3.0E-08	4.6E-07	2.9E-07	4.5E-10	9.6E-08	1.6E-10	6.0E-11
8	42	821	5.9E+03	1.7E-03	5.2E-01	315900	20000	1.3E-04	3.4E-07	2.5E-08	3.8E-07	2.4E-07	3.7E-10	7.9E-08	1.3E-10	4.9E-11
8	43	824	3.4E+03	1.0E-03	5.2E-01	315900	20000	7.5E-05	1.9E-07	1.4E-08	2.2E-07	1.4E-07	2.1E-10	4.5E-08	7.6E-11	2.8E-11
8	44	379	1.5E+05	4.2E-02	3.5E-01	319900	4000	3.7E-04	6.2E-06	5.4E-09	2.6E-05	1.0E-07	7.0E-11	1.5E-08	2.6E-11	1.1E-11
8	45	379	1.5E+05	4.3E-02	3.5E-01	323900	4000.1	4.0E-04	4.9E-06	7.1E-09	2.5E-05	1.2E-07	8.4E-11	1.8E-08	3.3E-11	1.5E-11
8	46	379	1.6E+05	4.4E-02	3.5E-01	327900	4000	4.8E-04	4.8E-06	1.1E-08	2.6E-05	1.7E-07	1.3E-10	2.8E-08	5.3E-11	2.4E-11
8	47	379	1.6E+05	4.4E-02	3.5E-01	331900	3999.9	5.4E-04	4.9E-06	1.1E-08	2.6E-05	1.7E-07	1.2E-10	2.6E-08	5.1E-11	2.4E-11
8	48	379	1.7E+05	4.5E-02	3.5E-01	335900	4000.1	5.8E-04	4.6E-06	1.1E-08	2.4E-05	1.7E-07	1.2E-10	2.5E-08	5.0E-11	2.5E-11
8	49	820	7.7E+03	2.3E-03	5.0E-01	335900	20000	1.6E-04	3.1E-07	2.6E-08	4.4E-07	3.2E-07	1.4E-09	6.9E-08	1.6E-10	5.5E-11
8	50	821	6.4E+03	1.9E-03	5.0E-01	335900	20000	1.3E-04	2.6E-07	2.1E-08	3.6E-07	2.6E-07	1.2E-09	5.7E-08	1.3E-10	4.5E-11
8	51	824	3.6E+03	1.1E-03	5.0E-01	335900	20000	7.6E-05	1.5E-07	1.2E-08	2.1E-07	1.5E-07	6.6E-10	3.3E-08	7.5E-11	2.6E-11
8	52	379	1.7E+05	4.5E-02	3.5E-01	339900	4000.1	6.0E-04	4.4E-06	1.2E-08	2.3E-05	1.9E-07	1.2E-10	2.5E-08	5.3E-11	2.7E-11
8	53	379	1.7E+05	4.6E-02	3.5E-01	343900	3999.9	6.1E-04	4.2E-06	1.2E-08	2.1E-05	1.9E-07	1.1E-10	2.3E-08	5.2E-11	2.7E-11
8	54	379	1.7E+05	4.7E-02	3.5E-01	347900	4000	6.1E-04	4.0E-06	1.1E-08	2.0E-05	2.0E-07	6.4E-10	2.6E-08	6.9E-11	2.6E-11
8	55	379	1.8E+05	4.7E-02	3.5E-01	351900	3999.9	6.2E-04	3.9E-06	9.9E-09	1.9E-05	2.4E-07	3.0E-09	4.2E-08	1.5E-10	2.2E-11
8	56	379	1.8E+05	4.8E-02	3.5E-01	355900	4000.2	6.1E-04	3.6E-06	8.8E-09	1.8E-05	2.0E-07	1.5E-09	2.6E-08	8.9E-11	2.1E-11
8	57	820	8.0E+03	2.3E-03	4.9E-01	355900	24000	1.9E-04	3.4E-07	2.5E-08	5.5E-07	4.4E-07	4.0E-09	7.4E-08	2.4E-10	5.8E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8	58	821	6.6E+03	1.9E-03	4.9E-01	355900	24000	1.6E-04	2.8E-07	2.0E-08	4.6E-07	3.6E-07	3.3E-09	6.1E-08	2.0E-10	4.8E-11
8	59	824	3.8E+03	1.1E-03	4.9E-01	355900	24000	9.2E-05	1.6E-07	1.2E-08	2.6E-07	2.1E-07	1.9E-09	3.5E-08	1.1E-10	2.7E-11
8	60	379	1.8E+05	4.8E-02	3.5E-01	359900	3999.8	6.1E-04	2.8E-06	8.5E-09	1.8E-05	1.9E-07	1.2E-09	2.3E-08	7.8E-11	2.0E-11
8	61	379	1.8E+05	4.8E-02	3.5E-01	363900	4000.1	6.1E-04	2.7E-06	8.4E-09	1.8E-05	1.9E-07	1.1E-09	2.1E-08	7.4E-11	2.1E-11
8	62	379	1.8E+05	4.8E-02	3.5E-01	367900	3999.9	6.1E-04	2.6E-06	8.1E-09	1.8E-05	1.9E-07	1.1E-09	2.0E-08	7.0E-11	2.0E-11
8	63	379	1.8E+05	4.9E-02	3.5E-01	371900	4000.2	6.1E-04	2.6E-06	7.9E-09	1.7E-05	1.9E-07	9.7E-10	1.8E-08	6.5E-11	2.0E-11
8	64	379	1.8E+05	4.9E-02	3.5E-01	375900	4000	6.1E-04	2.5E-06	7.6E-09	1.7E-05	1.9E-07	9.0E-10	1.7E-08	6.2E-11	2.0E-11
8	65	379	1.8E+05	4.9E-02	3.5E-01	379900	3999.8	6.1E-04	2.4E-06	7.5E-09	1.7E-05	1.9E-07	8.3E-10	1.6E-08	5.8E-11	2.0E-11
8	66	820	8.1E+03	2.4E-03	4.8E-01	379900	20000	1.6E-04	2.0E-07	1.8E-08	4.0E-07	3.6E-07	2.1E-09	3.9E-08	1.4E-10	4.5E-11
8	67	821	6.7E+03	2.0E-03	4.8E-01	379900	20000	1.4E-04	1.6E-07	1.5E-08	3.3E-07	2.9E-07	1.8E-09	3.3E-08	1.2E-10	3.8E-11
8	68	824	3.8E+03	1.1E-03	4.8E-01	379900	20000	7.7E-05	9.2E-08	8.3E-09	1.9E-07	1.7E-07	1.0E-09	1.9E-08	6.8E-11	2.1E-11
8	69	379	1.8E+05	4.9E-02	3.5E-01	383900	4000.3	6.1E-04	2.3E-06	7.5E-09	1.6E-05	1.9E-07	7.9E-10	1.5E-08	5.7E-11	2.0E-11
8	70	379	1.8E+05	4.9E-02	3.5E-01	387900	3999.9	6.1E-04	2.3E-06	7.3E-09	1.5E-05	1.9E-07	7.4E-10	1.4E-08	5.4E-11	2.0E-11
8	71	379	1.8E+05	5.0E-02	3.5E-01	391900	3999.9	6.1E-04	2.2E-06	7.1E-09	1.5E-05	1.9E-07	6.8E-10	1.3E-08	5.1E-11	2.0E-11
8	72	379	1.8E+05	5.0E-02	3.5E-01	395900	4000.1	6.1E-04	2.1E-06	7.1E-09	1.5E-05	2.0E-07	6.5E-10	1.2E-08	5.0E-11	2.0E-11
8	73	379	1.8E+05	5.0E-02	3.5E-01	399900	4000	6.2E-04	2.1E-06	7.4E-09	1.5E-05	2.1E-07	6.4E-10	1.2E-08	5.0E-11	2.1E-11
8	74	820	8.2E+03	2.4E-03	4.7E-01	399900	24000	2.0E-04	1.8E-07	1.9E-08	4.2E-07	4.5E-07	1.7E-09	3.2E-08	1.3E-10	5.3E-11
8	75	821	6.8E+03	2.0E-03	4.7E-01	399900	24000	1.6E-04	1.4E-07	1.6E-08	3.5E-07	3.7E-07	1.4E-09	2.6E-08	1.1E-10	4.4E-11
8	76	824	3.9E+03	1.1E-03	4.7E-01	399900	24000	9.3E-05	8.3E-08	9.0E-09	2.0E-07	2.1E-07	8.1E-10	1.5E-08	6.3E-11	2.5E-11
8	77	379	1.9E+05	5.0E-02	3.5E-01	403900	3999.9	6.2E-04	2.1E-06	7.7E-09	1.5E-05	2.2E-07	6.3E-10	1.2E-08	5.1E-11	2.2E-11
8	78	379	1.9E+05	5.0E-02	3.5E-01	407900	3999.9	6.3E-04	2.0E-06	7.5E-09	1.4E-05	2.2E-07	5.8E-10	1.1E-08	4.8E-11	2.1E-11
8	79	379	1.9E+05	5.0E-02	3.5E-01	411900	4000.1	6.3E-04	2.0E-06	7.2E-09	1.4E-05	2.2E-07	5.4E-10	1.0E-08	4.6E-11	2.1E-11
8	80	379	1.9E+05	5.1E-02	3.4E-01	415900	3999.9	6.4E-04	1.9E-06	7.0E-09	1.4E-05	2.2E-07	4.9E-10	9.0E-09	4.3E-11	2.0E-11
8	81	379	1.9E+05	5.1E-02	3.4E-01	419900	4000.1	6.4E-04	1.9E-06	6.6E-09	1.3E-05	2.2E-07	4.4E-10	8.2E-09	4.0E-11	1.9E-11
8	82	379	1.9E+05	5.1E-02	3.4E-01	423900	4000	6.3E-04	1.8E-06	5.9E-09	1.3E-05	2.0E-07	3.8E-10	7.1E-09	3.5E-11	1.8E-11
8	83	820	8.4E+03	2.4E-03	4.6E-01	423900	20000	1.7E-04	1.1E-07	1.5E-08	3.1E-07	4.3E-07	1.0E-09	1.9E-08	8.9E-11	4.3E-11
8	84	821	6.9E+03	2.0E-03	4.6E-01	423900	20000	1.4E-04	9.4E-08	1.2E-08	2.6E-07	3.6E-07	8.2E-10	1.5E-08	7.3E-11	3.5E-11
8	85	824	3.9E+03	1.1E-03	4.6E-01	423900	20000	7.8E-05	5.4E-08	6.9E-09	1.5E-07	2.0E-07	4.7E-10	8.7E-09	4.2E-11	2.0E-11
8	86	379	1.9E+05	5.1E-02	3.4E-01	427900	4000	6.3E-04	1.8E-06	6.2E-09	1.2E-05	2.2E-07	3.7E-10	6.9E-09	3.5E-11	1.8E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8	87	379	1.9E+05	5.1E-02	3.4E-01	431900	3999.9	6.5E-04	1.7E-06	8.3E-09	1.2E-05	3.0E-07	4.7E-10	8.7E-09	4.6E-11	2.5E-11
8	88	379	1.9E+05	5.1E-02	3.4E-01	435900	4000	6.6E-04	1.7E-06	8.8E-09	1.2E-05	3.3E-07	4.7E-10	8.7E-09	4.7E-11	2.6E-11
8	89	379	1.9E+05	5.2E-02	3.4E-01	439900	4000.2	6.7E-04	1.7E-06	9.0E-09	1.1E-05	3.5E-07	4.5E-10	8.5E-09	4.8E-11	2.7E-11
8	90	379	1.9E+05	5.2E-02	3.4E-01	443900	3999.9	6.7E-04	1.7E-06	9.1E-09	1.1E-05	3.7E-07	4.3E-10	8.1E-09	4.7E-11	2.7E-11
8	91	820	8.5E+03	2.5E-03	4.6E-01	443900	20000	1.7E-04	9.5E-08	1.4E-08	2.8E-07	5.3E-07	7.2E-10	1.3E-08	7.5E-11	4.2E-11
8	92	821	7.0E+03	2.0E-03	4.6E-01	443900	20000	1.4E-04	7.8E-08	1.2E-08	2.3E-07	4.4E-07	6.0E-10	1.1E-08	6.2E-11	3.5E-11
8	93	824	4.0E+03	1.2E-03	4.6E-01	443900	20000	7.8E-05	4.5E-08	6.7E-09	1.3E-07	2.5E-07	3.4E-10	6.4E-09	3.5E-11	2.0E-11
8	94	379	1.9E+05	5.2E-02	3.4E-01	447900	4000.1	6.7E-04	1.6E-06	9.2E-09	1.1E-05	3.9E-07	4.1E-10	7.6E-09	4.6E-11	2.7E-11
8	95	379	1.9E+05	5.2E-02	3.4E-01	451900	3999.9	6.8E-04	1.6E-06	9.3E-09	1.0E-05	4.1E-07	3.9E-10	7.2E-09	4.5E-11	2.7E-11
8	96	379	1.9E+05	5.2E-02	3.4E-01	455900	4000.1	6.8E-04	1.5E-06	9.4E-09	9.9E-06	4.4E-07	3.7E-10	6.9E-09	4.4E-11	2.8E-11
8	97	379	2.0E+05	5.2E-02	3.4E-01	459900	3999.9	6.8E-04	1.5E-06	9.5E-09	9.6E-06	4.7E-07	3.5E-10	6.5E-09	4.3E-11	2.8E-11
8	98	379	2.0E+05	5.2E-02	3.4E-01	463900	4000	6.8E-04	1.5E-06	9.7E-09	9.3E-06	5.1E-07	3.2E-10	6.1E-09	4.2E-11	2.8E-11
8	99	820	8.6E+03	2.5E-03	4.5E-01	463900	24000	2.0E-04	9.4E-08	1.8E-08	2.9E-07	9.4E-07	6.2E-10	1.2E-08	7.8E-11	5.0E-11
8	100	821	7.1E+03	2.0E-03	4.5E-01	463900	24000	1.7E-04	7.8E-08	1.5E-08	2.4E-07	7.8E-07	5.1E-10	1.0E-08	6.4E-11	4.2E-11
8	101	824	4.0E+03	1.2E-03	4.5E-01	463900	24000	9.4E-05	4.4E-08	8.6E-09	1.4E-07	4.4E-07	2.9E-10	5.7E-09	3.7E-11	2.4E-11
8	102	379	2.0E+05	5.3E-02	3.4E-01	467900	4000.1	6.8E-04	1.4E-06	1.0E-08	9.0E-06	5.5E-07	3.0E-10	5.7E-09	4.1E-11	2.8E-11
8	103	379	2.0E+05	5.3E-02	3.4E-01	471900	3999.8	6.8E-04	1.4E-06	1.0E-08	8.5E-06	6.0E-07	2.8E-10	5.5E-09	4.0E-11	2.8E-11
8	104	379	2.0E+05	5.3E-02	3.4E-01	475900	4000	6.8E-04	1.3E-06	1.0E-08	7.8E-06	6.2E-07	2.4E-10	4.9E-09	3.6E-11	2.6E-11
8	105	379	2.0E+05	5.3E-02	3.4E-01	479900	4000.1	6.8E-04	1.2E-06	9.9E-09	7.5E-06	6.8E-07	2.1E-10	5.1E-09	3.4E-11	2.5E-11
8	106	379	2.0E+05	5.3E-02	3.4E-01	483900	4000	6.8E-04	1.2E-06	1.0E-08	7.3E-06	8.0E-07	2.0E-10	6.5E-09	3.3E-11	2.4E-11
8	107	379	2.0E+05	5.3E-02	3.4E-01	487900	4000	6.8E-04	1.2E-06	1.1E-08	7.1E-06	9.9E-07	1.8E-10	9.7E-09	3.2E-11	2.4E-11
8	108	820	8.6E+03	2.5E-03	4.5E-01	487900	20000	1.7E-04	5.2E-08	1.7E-08	1.9E-07	2.2E-06	3.1E-10	3.5E-05	5.0E-11	3.7E-11
8	109	821	7.1E+03	2.1E-03	4.5E-01	487900	20000	1.4E-04	4.3E-08	1.4E-08	1.5E-07	1.8E-06	2.5E-10	2.9E-05	4.1E-11	3.0E-11
8	110	824	4.0E+03	1.2E-03	4.5E-01	487900	20000	7.8E-05	2.4E-08	8.0E-09	8.7E-08	1.0E-06	1.4E-10	1.7E-05	2.4E-11	1.7E-11
8	111	379	2.0E+05	5.3E-02	3.4E-01	491900	4000	6.8E-04	1.1E-06	1.1E-08	6.7E-06	1.4E-06	1.6E-10	1.8E-08	3.1E-11	2.4E-11
8	112	379	2.0E+05	5.3E-02	3.4E-01	495900	4000.1	6.8E-04	1.0E-06	8.9E-09	5.6E-06	2.2E-06	1.2E-10	4.5E-05	2.4E-11	1.9E-11
8	113	379	2.0E+05	5.3E-02	3.4E-01	499900	3200	5.4E-04	7.7E-07	1.1E-08	4.0E-06	3.3E-06	6.6E-11	7.1E-05	1.7E-11	1.4E-11
8	114	379	2.0E+05	5.3E-02	3.4E-01	503100	4799.9	8.1E-04	1.2E-06	2.8E-08	7.1E-06	4.0E-06	1.1E-10	4.5E-05	3.2E-11	2.8E-11
8	115	379	2.0E+05	5.3E-02	3.4E-01	507900	4000.2	6.8E-04	9.8E-07	2.6E-08	5.6E-06	1.7E-06	5.8E-11	1.9E-05	2.3E-11	2.1E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8	116	820	8.7E+03	2.5E-03	4.5E-01	507900	24000	2.0E-04	1.7E-08	3.2E-08	1.0E-07	1.6E-06	7.7E-11	2.5E-05	2.6E-11	2.3E-11
8	117	821	7.1E+03	2.1E-03	4.5E-01	507900	24000	1.6E-04	1.4E-08	2.6E-08	8.3E-08	1.3E-06	6.4E-11	2.1E-05	2.2E-11	1.9E-11
8	118	824	4.1E+03	1.2E-03	4.5E-01	507900	24000	9.4E-05	8.1E-09	1.5E-08	4.8E-08	7.5E-07	3.6E-11	1.2E-05	1.2E-11	1.1E-11
8	119	379	2.0E+05	5.3E-02	3.4E-01	511900	3999.7	6.8E-04	9.4E-07	2.8E-08	5.3E-06	1.1E-06	4.0E-11	1.3E-05	2.0E-11	1.9E-11
8	120	379	2.0E+05	5.3E-02	3.4E-01	515900	4000.2	6.8E-04	9.0E-07	3.0E-08	5.0E-06	8.2E-07	3.0E-11	1.0E-05	1.9E-11	1.8E-11
8	121	379	2.0E+05	5.4E-02	3.4E-01	519900	3999.9	6.8E-04	8.8E-07	3.1E-08	4.8E-06	6.3E-07	2.5E-11	8.0E-06	1.6E-11	1.5E-11
8	122	379	2.0E+05	5.4E-02	3.4E-01	523900	4000	6.8E-04	8.5E-07	3.4E-08	4.7E-06	5.4E-07	2.0E-11	6.5E-06	1.6E-11	1.6E-11
8	123	379	2.0E+05	5.4E-02	3.4E-01	527900	4000.1	6.8E-04	7.8E-07	3.7E-08	4.6E-06	4.6E-07	1.7E-11	5.5E-06	1.7E-11	1.7E-11
8	124	379	2.0E+05	5.4E-02	3.4E-01	531900	3999.9	6.8E-04	7.6E-07	4.2E-08	4.7E-06	4.1E-07	1.5E-11	4.9E-06	1.9E-11	1.8E-11
8	125	820	8.7E+03	2.5E-03	4.4E-01	531900	20000	1.7E-04	1.0E-08	5.1E-08	7.3E-08	5.9E-07	2.4E-11	7.9E-06	2.3E-11	2.3E-11
8	126	821	7.2E+03	2.1E-03	4.4E-01	531900	20000	1.4E-04	8.7E-09	4.2E-08	6.0E-08	4.9E-07	2.0E-11	6.5E-06	1.9E-11	1.9E-11
8	127	824	4.1E+03	1.2E-03	4.4E-01	531900	20000	7.8E-05	4.9E-09	2.4E-08	3.4E-08	2.8E-07	1.1E-11	3.7E-06	1.1E-11	1.1E-11
8	128	379	2.0E+05	5.4E-02	3.4E-01	535900	4000	6.8E-04	6.1E-07	4.7E-08	4.7E-06	3.7E-07	1.4E-11	4.4E-06	1.9E-11	1.9E-11
8	129	379	2.0E+05	5.4E-02	3.4E-01	539900	4000.1	6.8E-04	5.7E-07	5.2E-08	4.8E-06	3.4E-07	1.2E-11	4.0E-06	2.2E-11	2.2E-11
8	130	379	2.0E+05	5.4E-02	3.4E-01	543900	3999.9	6.8E-04	5.7E-07	5.7E-08	4.8E-06	3.2E-07	1.2E-11	3.7E-06	2.3E-11	2.3E-11
8	131	379	2.0E+05	5.4E-02	3.4E-01	547900	4000	6.8E-04	5.6E-07	6.1E-08	4.7E-06	2.9E-07	1.1E-11	3.4E-06	2.4E-11	2.4E-11
8	132	379	2.0E+05	5.4E-02	3.4E-01	551900	4000	6.8E-04	5.5E-07	6.5E-08	4.7E-06	2.7E-07	1.0E-11	3.1E-06	2.6E-11	2.6E-11
8	133	820	8.8E+03	2.5E-03	4.4E-01	551900	20000	1.7E-04	1.1E-08	6.6E-08	7.6E-08	3.7E-07	1.5E-11	4.6E-06	3.1E-11	3.1E-11
8	134	821	7.3E+03	2.1E-03	4.4E-01	551900	20000	1.4E-04	9.3E-09	5.5E-08	6.2E-08	3.1E-07	1.2E-11	3.8E-06	2.5E-11	2.5E-11
8	135	824	4.1E+03	1.2E-03	4.4E-01	551900	20000	7.8E-05	5.3E-09	3.1E-08	3.6E-08	1.8E-07	7.0E-12	2.2E-06	1.5E-11	1.4E-11
8	136	379	2.0E+05	5.4E-02	3.4E-01	555900	4000	6.8E-04	5.4E-07	6.5E-08	4.7E-06	2.5E-07	9.5E-12	2.9E-06	2.7E-11	2.7E-11
8	137	379	2.0E+05	5.5E-02	3.4E-01	559900	3999.9	6.8E-04	5.4E-07	5.2E-08	4.6E-06	2.3E-07	8.6E-12	2.7E-06	2.9E-11	2.9E-11
8	138	379	2.0E+05	5.5E-02	3.5E-01	563900	4000.1	6.8E-04	5.3E-07	4.8E-08	4.6E-06	2.2E-07	9.1E-12	2.5E-06	3.0E-11	3.1E-11
8	139	379	2.0E+05	5.5E-02	3.5E-01	567900	4000.1	6.8E-04	5.2E-07	4.7E-08	4.5E-06	2.1E-07	7.7E-12	2.4E-06	3.2E-11	3.2E-11
8	140	379	2.0E+05	5.5E-02	3.5E-01	571900	3999.9	6.8E-04	5.1E-07	4.7E-08	4.4E-06	2.0E-07	8.2E-12	2.3E-06	3.3E-11	3.3E-11
8	141	820	8.8E+03	2.5E-03	4.4E-01	571900	24000	2.0E-04	1.5E-08	6.9E-08	9.5E-08	3.0E-07	1.3E-11	3.6E-06	4.6E-11	4.7E-11
8	142	821	7.3E+03	2.1E-03	4.4E-01	571900	24000	1.6E-04	1.2E-08	5.7E-08	7.8E-08	2.5E-07	1.0E-11	3.0E-06	3.8E-11	3.8E-11
8	143	824	4.2E+03	1.2E-03	4.4E-01	571900	24000	9.3E-05	7.0E-09	3.3E-08	4.5E-08	1.4E-07	5.9E-12	1.7E-06	2.2E-11	2.2E-11
8	144	379	2.0E+05	5.5E-02	3.5E-01	575900	4000.1	6.8E-04	5.0E-07	4.6E-08	4.3E-06	1.9E-07	7.7E-12	2.1E-06	3.4E-11	3.5E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8	145	379	2.0E+05	5.5E-02	3.5E-01	579900	3999.9	6.8E-04	4.9E-07	4.6E-08	4.3E-06	1.8E-07	7.7E-12	2.0E-06	3.6E-11	3.6E-11
8	146	379	2.0E+05	5.5E-02	3.5E-01	583900	4000	6.8E-04	4.8E-07	4.6E-08	4.2E-06	1.7E-07	7.3E-12	1.9E-06	3.7E-11	3.7E-11
8	147	379	2.0E+05	5.5E-02	3.5E-01	587900	4000.2	6.8E-04	4.7E-07	4.6E-08	4.1E-06	1.6E-07	6.8E-12	1.8E-06	3.8E-11	3.9E-11
8	148	379	2.1E+05	5.5E-02	3.5E-01	591900	4000	6.8E-04	4.5E-07	4.5E-08	4.0E-06	1.5E-07	7.3E-12	1.7E-06	3.9E-11	4.0E-11
8	149	379	2.1E+05	5.5E-02	3.5E-01	595900	7999.9	1.4E-03	8.7E-07	9.0E-08	7.6E-06	2.8E-07	1.2E-11	3.1E-06	8.2E-11	8.2E-11
8	150	820	8.9E+03	2.6E-03	4.4E-01	595900	7999.9	6.6E-05	5.2E-09	2.2E-08	3.2E-08	7.7E-08	3.4E-12	9.1E-07	1.7E-11	1.7E-11
8	151	821	7.3E+03	2.1E-03	4.4E-01	595900	7999.9	5.4E-05	4.3E-09	1.8E-08	2.7E-08	6.4E-08	2.8E-12	7.5E-07	1.4E-11	1.4E-11
8	152	824	4.2E+03	1.2E-03	4.4E-01	595900	7999.9	3.1E-05	2.4E-09	1.0E-08	1.5E-08	3.6E-08	1.6E-12	4.3E-07	8.2E-12	8.2E-12
8B	1	379	2.0E+06	6.3E-01	3.3E-01	175900	4000	1.5E-04	5.2E-05	1.1E-05	5.5E-05	5.7E-05	9.1E-09	7.9E-07	1.5E-13	1.5E-13
8B	2	379	5.4E+05	1.7E-01	3.1E-01	179900	3999.9	4.0E-03	1.2E-03	2.2E-05	9.4E-04	1.1E-03	4.0E-06	2.8E-04	1.5E-10	1.5E-10
8B	3	377	2.8E+07	8.9E+00	3.1E-01	180540	3364.4	3.9E-01	1.1E-01	1.4E-03	9.1E-02	1.1E-01	4.1E-04	2.9E-02	1.5E-08	1.5E-08
8B	4	377	8.1E+06	2.2E+00	2.3E-01	183900	3764.4	3.4E-01	9.0E-02	7.3E-04	9.2E-02	1.0E-01	2.5E-03	2.2E-02	5.8E-08	5.8E-08
8B	5	379	8.0E+04	2.2E-02	2.3E-01	183900	2732.9	2.7E-03	7.2E-04	5.4E-06	7.0E-04	8.3E-04	1.8E-05	1.8E-04	4.0E-10	4.0E-10
8B	6	379	7.0E+04	1.7E-02	2.1E-01	186630	5267.1	1.6E-03	4.1E-04	3.6E-06	1.1E-03	4.0E-04	1.1E-05	8.8E-05	3.0E-10	3.0E-10
8B	7	377	7.1E+06	1.7E+00	2.1E-01	187660	4235.6	9.6E-02	2.5E-02	1.8E-04	9.1E-02	2.6E-02	3.7E-04	4.8E-03	1.3E-08	1.3E-08
8B	8	377	6.9E+06	1.9E+00	2.4E-01	191900	4000.1	2.0E-02	5.2E-03	1.3E-04	3.3E-02	1.2E-02	1.2E-05	7.4E-04	3.2E-09	3.2E-09
8B	9	379	6.8E+04	1.8E-02	2.4E-01	191900	4000.1	2.0E-04	5.0E-05	1.3E-06	3.2E-04	1.2E-04	1.2E-07	7.2E-06	3.2E-11	3.2E-11
8B	10	377	7.3E+06	1.9E+00	2.5E-01	195900	4000	8.2E-03	2.1E-03	7.4E-05	9.8E-03	9.0E-03	9.2E-05	3.9E-04	4.1E-09	4.1E-09
8B	11	379	7.2E+04	1.9E-02	2.5E-01	195900	4000	8.2E-05	2.1E-05	7.4E-07	9.8E-05	9.0E-05	9.1E-07	3.9E-06	4.1E-11	4.1E-11
8B	12	377	6.1E+06	1.7E+00	2.5E-01	199900	4000	7.3E-03	1.2E-03	5.6E-05	7.1E-03	5.4E-03	8.3E-06	1.9E-04	5.3E-09	5.3E-09
8B	13	379	6.0E+04	1.6E-02	2.5E-01	199900	4292.8	7.8E-05	1.3E-05	6.7E-07	7.5E-05	5.8E-05	1.2E-07	2.1E-06	6.2E-11	6.2E-11
8B	14	377	7.9E+06	2.1E+00	2.6E-01	203900	3189	4.5E-03	6.2E-04	3.5E-05	1.9E-03	2.8E-03	2.7E-05	1.3E-04	3.4E-09	3.4E-09
8B	15	379	7.9E+04	2.1E-02	2.6E-01	204190	3707.2	5.3E-05	7.3E-06	2.9E-07	1.9E-05	2.9E-05	2.5E-07	1.6E-06	2.9E-11	2.9E-11
8B	16	377	7.5E+06	2.1E+00	2.6E-01	207090	811	1.4E-03	2.4E-04	3.9E-06	4.0E-04	5.7E-04	2.1E-06	5.8E-05	3.8E-10	3.8E-10
8B	17	377	3.8E+06	1.1E+00	2.7E-01	207900	5063.7	1.5E-02	6.5E-03	4.3E-05	6.3E-03	6.7E-03	9.4E-06	1.7E-03	3.7E-09	3.7E-09
8B	18	379	4.9E+04	1.4E-02	2.7E-01	207900	4000.1	1.6E-04	7.0E-05	4.6E-07	6.6E-05	7.0E-05	9.8E-08	1.8E-05	3.9E-11	3.9E-11
8B	19	820	2.9E+03	7.5E-04	7.5E-01	211380	20521	1.2E-05	3.2E-06	4.8E-08	3.4E-06	2.7E-06	4.6E-09	1.4E-07	1.3E-10	2.0E-11
8B	20	821	2.4E+03	6.2E-04	7.5E-01	211380	20521	1.0E-05	2.7E-06	4.0E-08	2.8E-06	2.2E-06	3.8E-09	1.1E-07	1.1E-10	1.7E-11
8B	21	824	1.3E+03	3.5E-04	7.5E-01	211380	20521	5.7E-06	1.5E-06	2.3E-08	1.6E-06	1.3E-06	2.2E-09	6.6E-08	6.3E-11	9.5E-12

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	22	377	4.0E+05	1.4E-01	4.3E-01	212960	4179.3	1.5E-04	2.4E-05	3.9E-08	8.6E-05	4.4E-04	7.9E-09	1.2E-06	3.0E-12	2.9E-12
8B	23	377	4.2E+05	1.4E-01	4.1E-01	217140	2757	2.5E-05	1.3E-05	5.6E-09	1.1E-04	4.1E-04	2.3E-10	2.0E-07	5.0E-13	5.2E-13
8B	24	377	4.3E+05	1.4E-01	3.9E-01	219900	3999.9	1.1E-05	2.4E-05	3.3E-09	1.6E-04	7.0E-04	0.0E+00	1.2E-07	3.5E-13	3.7E-13
8B	25	377	4.3E+05	1.4E-01	3.9E-01	223900	4000	1.4E-06	3.3E-05	2.3E-10	1.5E-04	7.0E-04	0.0E+00	3.0E-08	4.3E-14	5.0E-14
8B	26	377	4.1E+05	1.3E-01	3.8E-01	227900	4000.1	2.4E-07	3.9E-05	0.0E+00	1.3E-04	7.0E-04	0.0E+00	1.1E-08	1.4E-14	2.1E-14
8B	27	377	4.0E+05	1.3E-01	3.8E-01	231900	4000.1	1.2E-07	4.9E-05	0.0E+00	1.4E-04	6.6E-04	0.0E+00	2.2E-08	1.4E-14	1.4E-14
8B	28	820	3.4E+03	8.9E-04	7.0E-01	231900	24000	1.7E-05	3.6E-06	7.2E-08	4.9E-06	3.0E-06	1.2E-09	4.7E-08	1.3E-10	5.6E-11
8B	29	821	2.8E+03	7.3E-04	7.0E-01	231900	24000	1.4E-05	3.0E-06	6.0E-08	4.1E-06	2.5E-06	1.0E-09	3.9E-08	1.1E-10	4.6E-11
8B	30	824	1.6E+03	4.2E-04	7.0E-01	231900	24000	7.9E-06	1.7E-06	3.4E-08	2.3E-06	1.4E-06	5.8E-10	2.2E-08	6.2E-11	2.6E-11
8B	31	377	3.8E+05	1.2E-01	3.7E-01	235900	4000.1	6.0E-08	6.0E-05	0.0E+00	1.5E-04	3.6E-04	0.0E+00	1.5E-08	7.1E-15	0.0E+00
8B	32	377	3.8E+05	1.2E-01	3.7E-01	239900	3999.9	0.0E+00	6.8E-05	0.0E+00	1.6E-04	2.5E-04	0.0E+00	1.1E-08	0.0E+00	0.0E+00
8B	33	377	3.7E+05	1.2E-01	3.7E-01	243900	4000	0.0E+00	7.1E-05	0.0E+00	1.4E-04	2.2E-04	0.0E+00	1.5E-08	0.0E+00	0.0E+00
8B	34	377	3.7E+05	1.2E-01	3.6E-01	247900	4000	0.0E+00	7.0E-05	0.0E+00	1.3E-04	1.9E-04	0.0E+00	7.5E-09	0.0E+00	0.0E+00
8B	35	377	3.7E+05	1.2E-01	3.6E-01	251900	3999.9	0.0E+00	6.6E-05	0.0E+00	1.2E-04	1.6E-04	0.0E+00	1.2E-07	3.2E-12	4.6E-12
8B	36	377	3.6E+05	1.1E-01	3.5E-01	255900	4000	6.0E-08	6.8E-05	0.0E+00	1.1E-04	1.4E-04	0.0E+00	1.9E-06	6.5E-11	9.2E-11
8B	37	820	3.7E+03	9.9E-04	6.6E-01	255900	20000	1.5E-05	6.5E-07	1.5E-07	1.7E-06	7.4E-07	1.8E-10	2.3E-08	8.1E-11	6.0E-11
8B	38	821	3.1E+03	8.2E-04	6.6E-01	255900	20000	1.2E-05	5.4E-07	1.2E-07	1.4E-06	6.1E-07	1.5E-10	1.9E-08	6.7E-11	5.0E-11
8B	39	824	1.8E+03	4.7E-04	6.6E-01	255900	20000	7.0E-06	3.1E-07	7.0E-08	8.1E-07	3.5E-07	8.5E-11	1.1E-08	3.8E-11	2.8E-11
8B	40	377	3.6E+05	1.1E-01	3.5E-01	259900	4000.1	1.8E-07	8.7E-05	0.0E+00	9.9E-05	1.4E-04	0.0E+00	9.8E-06	3.6E-10	2.3E-10
8B	41	377	3.6E+05	1.1E-01	3.4E-01	263900	4000	1.5E-06	9.2E-05	9.1E-09	8.9E-05	1.3E-04	0.0E+00	2.0E-05	4.0E-10	8.1E-11
8B	42	377	3.6E+05	1.1E-01	3.4E-01	267900	4000.1	8.2E-06	9.8E-05	2.8E-08	8.0E-05	1.1E-04	0.0E+00	2.4E-05	9.5E-11	3.1E-11
8B	43	377	3.7E+05	1.1E-01	3.4E-01	271900	3999.8	1.8E-05	1.1E-04	4.7E-08	7.3E-05	9.0E-05	0.0E+00	2.8E-05	5.7E-11	4.4E-11
8B	44	377	3.7E+05	1.1E-01	3.4E-01	275900	4000.2	2.9E-05	1.3E-04	6.3E-08	6.7E-05	7.5E-05	0.0E+00	3.3E-05	7.6E-11	6.6E-11
8B	45	820	4.1E+03	1.1E-03	6.3E-01	275900	20000	1.6E-05	3.5E-07	8.4E-08	1.3E-06	6.1E-07	7.9E-11	1.8E-08	8.3E-11	7.1E-11
8B	46	821	3.4E+03	9.0E-04	6.3E-01	275900	20000	1.3E-05	2.9E-07	6.9E-08	1.1E-06	5.0E-07	6.5E-11	1.5E-08	6.9E-11	5.9E-11
8B	47	824	1.9E+03	5.1E-04	6.3E-01	275900	20000	7.3E-06	1.7E-07	3.9E-08	6.2E-07	2.9E-07	3.7E-11	8.3E-09	3.9E-11	3.4E-11
8B	48	377	3.8E+05	1.1E-01	3.4E-01	279900	3999.9	3.9E-05	1.4E-04	7.1E-08	6.2E-05	6.2E-05	0.0E+00	3.6E-05	9.8E-11	8.7E-11
8B	49	377	3.8E+05	1.1E-01	3.4E-01	283900	4000.1	4.9E-05	1.5E-04	8.1E-08	5.6E-05	5.2E-05	2.3E-10	3.9E-05	1.3E-10	1.1E-10
8B	50	377	4.0E+05	1.2E-01	3.5E-01	287900	3999.7	9.7E-05	1.4E-04	1.5E-07	4.9E-05	4.2E-05	0.0E+00	3.8E-05	2.6E-10	2.4E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	51	377	4.3E+05	1.2E-01	3.6E-01	291900	4000.1	1.5E-04	1.2E-04	1.7E-07	4.4E-05	3.4E-05	2.3E-10	3.2E-05	3.3E-10	3.0E-10
8B	52	377	4.5E+05	1.2E-01	3.6E-01	295900	4000.2	2.0E-04	1.3E-04	1.9E-07	6.7E-05	2.9E-05	2.3E-10	3.5E-05	4.2E-10	3.8E-10
8B	53	820	4.4E+03	1.2E-03	5.9E-01	295900	24000	1.9E-05	2.9E-07	4.8E-08	1.2E-06	7.1E-07	4.3E-11	2.1E-08	9.4E-11	8.6E-11
8B	54	821	3.7E+03	1.0E-03	5.9E-01	295900	24000	1.6E-05	2.4E-07	4.0E-08	9.7E-07	5.9E-07	3.6E-11	1.7E-08	7.8E-11	7.1E-11
8B	55	824	2.1E+03	5.7E-04	5.9E-01	295900	24000	9.2E-06	1.4E-07	2.3E-08	5.5E-07	3.3E-07	2.0E-11	9.9E-09	4.4E-11	4.1E-11
8B	56	377	4.6E+05	1.2E-01	3.7E-01	299900	4000	2.2E-04	1.2E-04	1.9E-07	5.5E-05	2.4E-05	0.0E+00	3.2E-05	4.4E-10	4.1E-10
8B	57	377	4.7E+05	1.2E-01	3.6E-01	303900	3999.8	2.2E-04	1.1E-04	1.6E-07	5.5E-05	2.0E-05	0.0E+00	2.8E-05	4.2E-10	3.9E-10
8B	58	377	4.7E+05	1.2E-01	3.6E-01	307900	3999.9	2.2E-04	8.8E-05	1.3E-07	5.7E-05	1.7E-05	4.7E-10	2.2E-05	3.6E-10	3.4E-10
8B	59	377	4.8E+05	1.2E-01	3.6E-01	311900	6787.5	3.9E-04	1.2E-04	1.9E-07	9.6E-05	2.5E-05	0.0E+00	3.1E-05	5.9E-10	5.6E-10
8B	60	377	6.9E+05	1.8E-01	3.5E-01	318690	1212.6	1.2E-04	2.0E-05	6.8E-08	3.2E-05	5.4E-06	0.0E+00	4.5E-06	2.2E-10	2.1E-10
8B	61	377	4.9E+05	1.4E-01	3.6E-01	319900	4000	2.9E-04	4.6E-05	7.1E-08	9.7E-05	1.2E-05	0.0E+00	1.0E-05	2.6E-10	2.5E-10
8B	62	820	3.7E+03	1.4E-03	5.5E-01	319900	20000	1.7E-05	1.5E-07	1.8E-08	4.8E-07	4.6E-07	1.5E-11	1.5E-08	6.0E-11	5.8E-11
8B	63	821	3.0E+03	1.1E-03	5.5E-01	319900	20000	1.4E-05	1.3E-07	1.5E-08	4.0E-07	3.8E-07	1.2E-11	1.2E-08	5.0E-11	4.8E-11
8B	64	824	1.7E+03	6.4E-04	5.5E-01	319900	20000	8.0E-06	7.2E-08	8.3E-09	2.3E-07	2.1E-07	7.0E-12	7.1E-09	2.9E-11	2.7E-11
8B	65	377	4.4E+05	1.4E-01	3.6E-01	323900	4000	2.7E-04	4.7E-05	6.4E-08	8.5E-05	1.1E-05	2.3E-10	1.0E-05	2.7E-10	2.6E-10
8B	66	377	4.4E+05	1.4E-01	3.6E-01	327900	4000	2.6E-04	4.0E-05	5.6E-08	8.6E-05	1.0E-05	0.0E+00	8.7E-06	2.5E-10	2.4E-10
8B	67	377	4.4E+05	1.4E-01	3.6E-01	331900	4000	2.6E-04	3.7E-05	5.7E-08	6.4E-05	9.7E-06	0.0E+00	8.1E-06	2.7E-10	2.6E-10
8B	68	377	4.4E+05	1.4E-01	3.5E-01	335900	4000.2	2.6E-04	3.4E-05	5.7E-08	6.1E-05	9.1E-06	0.0E+00	7.3E-06	2.8E-10	2.7E-10
8B	69	377	4.3E+05	1.4E-01	3.5E-01	339900	3999.9	2.6E-04	2.8E-05	5.2E-08	7.0E-05	8.7E-06	0.0E+00	5.7E-06	2.6E-10	2.5E-10
8B	70	820	3.8E+03	1.4E-03	5.6E-01	339900	24000	2.0E-05	2.5E-07	1.5E-08	6.0E-07	7.0E-07	3.6E-11	1.8E-08	6.9E-11	6.7E-11
8B	71	821	3.2E+03	1.2E-03	5.6E-01	339900	24000	1.7E-05	2.0E-07	1.2E-08	5.0E-07	5.8E-07	3.0E-11	1.5E-08	5.7E-11	5.5E-11
8B	72	824	1.8E+03	6.7E-04	5.6E-01	339900	24000	9.5E-06	1.2E-07	7.0E-09	2.8E-07	3.3E-07	1.7E-11	8.3E-09	3.3E-11	3.1E-11
8B	73	377	4.3E+05	1.4E-01	3.4E-01	343900	4000	2.6E-04	2.7E-05	5.4E-08	1.2E-04	8.9E-06	7.0E-10	4.3E-06	2.3E-10	2.2E-10
8B	74	377	4.3E+05	1.4E-01	3.4E-01	347900	3999.8	2.6E-04	2.3E-05	4.7E-08	6.2E-05	7.8E-06	0.0E+00	4.4E-06	2.5E-10	2.4E-10
8B	75	377	4.3E+05	1.3E-01	3.4E-01	351900	4000.1	2.6E-04	2.3E-05	4.4E-08	8.7E-05	8.0E-06	0.0E+00	3.8E-06	2.4E-10	2.4E-10
8B	76	377	4.3E+05	1.3E-01	3.4E-01	355900	4000	2.6E-04	2.1E-05	4.1E-08	9.6E-05	8.0E-06	0.0E+00	3.1E-06	2.3E-10	2.3E-10
8B	77	377	4.2E+05	1.3E-01	3.4E-01	359900	4000	2.6E-04	1.8E-05	4.1E-08	6.9E-05	7.5E-06	0.0E+00	2.9E-06	2.4E-10	2.4E-10
8B	78	377	4.1E+05	1.3E-01	3.4E-01	363900	4000.1	2.6E-04	1.8E-05	3.6E-08	9.6E-05	7.7E-06	0.0E+00	2.3E-06	2.2E-10	2.2E-10
8B	79	820	3.9E+03	1.4E-03	5.5E-01	363900	20000	1.7E-05	2.3E-07	9.7E-09	4.9E-07	7.0E-07	2.0E-11	1.4E-08	5.6E-11	5.5E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	80	821	3.2E+03	1.2E-03	5.5E-01	363900	20000	1.4E-05	1.9E-07	8.0E-09	4.0E-07	5.8E-07	1.7E-11	1.1E-08	4.6E-11	4.6E-11
8B	81	824	1.8E+03	6.7E-04	5.5E-01	363900	20000	7.9E-06	1.1E-07	4.6E-09	2.3E-07	3.3E-07	9.6E-12	6.4E-09	2.6E-11	2.6E-11
8B	82	377	4.1E+05	1.3E-01	3.4E-01	367900	4000	2.6E-04	1.6E-05	3.7E-08	8.1E-05	7.5E-06	0.0E+00	2.1E-06	2.3E-10	2.3E-10
8B	83	377	4.1E+05	1.3E-01	3.4E-01	371900	3999.8	2.6E-04	1.5E-05	3.5E-08	8.4E-05	7.4E-06	4.7E-10	1.8E-06	2.2E-10	2.2E-10
8B	84	377	4.2E+05	1.3E-01	3.3E-01	375900	4000.2	2.6E-04	1.3E-05	3.7E-08	5.7E-05	7.1E-06	0.0E+00	1.7E-06	2.4E-10	2.3E-10
8B	85	377	4.2E+05	1.3E-01	3.3E-01	379900	3999.8	2.6E-04	1.3E-05	3.4E-08	7.2E-05	7.3E-06	0.0E+00	1.4E-06	2.3E-10	2.3E-10
8B	86	377	4.2E+05	1.3E-01	3.3E-01	383900	4000.3	2.6E-04	1.3E-05	3.4E-08	8.2E-05	7.3E-06	0.0E+00	1.3E-06	2.2E-10	2.2E-10
8B	87	820	3.9E+03	1.4E-03	5.4E-01	383900	20000	1.7E-05	2.6E-07	8.4E-09	4.8E-07	8.1E-07	1.3E-11	1.3E-08	5.4E-11	5.4E-11
8B	88	821	3.2E+03	1.2E-03	5.4E-01	383900	20000	1.4E-05	2.1E-07	6.9E-09	4.0E-07	6.7E-07	1.1E-11	1.0E-08	4.5E-11	4.5E-11
8B	89	824	1.8E+03	6.7E-04	5.4E-01	383900	20000	7.8E-06	1.2E-07	3.9E-09	2.3E-07	3.8E-07	6.1E-12	5.9E-09	2.6E-11	2.6E-11
8B	90	377	4.2E+05	1.3E-01	3.3E-01	387900	3999.9	2.6E-04	1.2E-05	3.3E-08	6.8E-05	7.1E-06	0.0E+00	1.2E-06	2.3E-10	2.3E-10
8B	91	377	4.2E+05	1.3E-01	3.3E-01	391900	4000	2.6E-04	1.1E-05	3.4E-08	6.8E-05	7.2E-06	0.0E+00	1.1E-06	2.3E-10	2.3E-10
8B	92	377	4.2E+05	1.3E-01	3.3E-01	395900	3999.8	2.6E-04	1.1E-05	3.2E-08	7.2E-05	7.1E-06	0.0E+00	9.3E-07	2.2E-10	2.2E-10
8B	93	377	4.2E+05	1.3E-01	3.3E-01	399900	4000.2	2.6E-04	9.0E-06	3.6E-08	4.1E-05	7.6E-06	0.0E+00	9.3E-07	2.5E-10	2.5E-10
8B	94	377	4.2E+05	1.3E-01	3.3E-01	403900	3999.9	2.6E-04	8.7E-06	3.7E-08	3.8E-05	7.8E-06	0.0E+00	9.1E-07	2.6E-10	2.6E-10
8B	95	820	3.9E+03	1.4E-03	5.2E-01	403900	24000	2.0E-05	3.5E-07	9.1E-09	5.7E-07	1.2E-06	9.7E-12	1.3E-08	6.3E-11	6.3E-11
8B	96	821	3.2E+03	1.2E-03	5.2E-01	403900	24000	1.6E-05	2.9E-07	7.5E-09	4.7E-07	9.5E-07	8.0E-12	1.1E-08	5.2E-11	5.2E-11
8B	97	824	1.8E+03	6.7E-04	5.2E-01	403900	24000	9.4E-06	1.6E-07	4.3E-09	2.7E-07	5.4E-07	4.6E-12	6.3E-09	2.9E-11	3.0E-11
8B	98	377	4.2E+05	1.3E-01	3.3E-01	407900	3999.9	2.6E-04	8.2E-06	3.7E-08	3.7E-05	8.1E-06	0.0E+00	8.1E-07	2.6E-10	2.6E-10
8B	99	377	4.3E+05	1.3E-01	3.3E-01	411900	4000.1	2.6E-04	7.8E-06	3.7E-08	3.6E-05	8.2E-06	0.0E+00	7.5E-07	2.6E-10	2.6E-10
8B	100	377	4.3E+05	1.3E-01	3.3E-01	415900	4000.1	2.7E-04	7.5E-06	3.7E-08	3.4E-05	8.2E-06	4.7E-10	6.9E-07	2.6E-10	2.6E-10
8B	101	377	4.3E+05	1.3E-01	3.3E-01	419900	4000	2.7E-04	7.2E-06	3.7E-08	3.3E-05	8.4E-06	0.0E+00	6.3E-07	2.6E-10	2.6E-10
8B	102	377	4.3E+05	1.3E-01	3.3E-01	423900	3999.9	2.7E-04	6.9E-06	3.7E-08	3.2E-05	8.6E-06	0.0E+00	5.8E-07	2.6E-10	2.6E-10
8B	103	377	4.3E+05	1.3E-01	3.3E-01	427900	3999.9	2.7E-04	6.5E-06	3.7E-08	3.1E-05	8.7E-06	0.0E+00	5.3E-07	2.6E-10	2.7E-10
8B	104	820	4.0E+03	1.4E-03	5.1E-01	427900	20000	1.7E-05	2.6E-07	7.1E-09	4.7E-07	1.2E-06	5.2E-12	9.9E-09	5.0E-11	5.1E-11
8B	105	821	3.3E+03	1.2E-03	5.1E-01	427900	20000	1.4E-05	2.2E-07	5.9E-09	3.9E-07	9.7E-07	4.3E-12	8.2E-09	4.1E-11	4.2E-11
8B	106	824	1.9E+03	6.7E-04	5.1E-01	427900	20000	7.8E-06	1.2E-07	3.4E-09	2.2E-07	5.6E-07	2.4E-12	4.7E-09	2.4E-11	2.4E-11
8B	107	377	4.3E+05	1.3E-01	3.3E-01	431900	4000.3	2.7E-04	6.1E-06	3.8E-08	3.0E-05	9.0E-06	0.0E+00	5.0E-07	2.6E-10	2.7E-10
8B	108	377	4.3E+05	1.3E-01	3.3E-01	435900	3999.8	2.7E-04	5.8E-06	3.8E-08	2.9E-05	9.3E-06	0.0E+00	4.6E-07	2.6E-10	2.7E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	109	377	4.3E+05	1.3E-01	3.3E-01	439900	4000.1	2.7E-04	5.6E-06	3.9E-08	2.8E-05	9.6E-06	0.0E+00	4.4E-07	2.7E-10	2.7E-10
8B	110	377	4.3E+05	1.3E-01	3.3E-01	443900	3999.8	2.7E-04	5.3E-06	4.0E-08	2.7E-05	1.0E-05	0.0E+00	4.1E-07	2.7E-10	2.7E-10
8B	111	377	4.3E+05	1.3E-01	3.3E-01	447900	4000.2	2.7E-04	5.1E-06	4.1E-08	2.6E-05	1.1E-05	0.0E+00	3.8E-07	2.7E-10	2.8E-10
8B	112	820	4.0E+03	1.4E-03	5.0E-01	447900	24000	2.0E-05	2.3E-07	8.9E-09	5.7E-07	1.9E-06	4.0E-12	1.1E-08	5.8E-11	5.9E-11
8B	113	821	3.3E+03	1.2E-03	5.0E-01	447900	24000	1.6E-05	1.9E-07	7.3E-09	4.7E-07	1.6E-06	3.3E-12	8.7E-09	4.8E-11	4.9E-11
8B	114	824	1.9E+03	6.7E-04	5.0E-01	447900	24000	9.3E-06	1.1E-07	4.2E-09	2.7E-07	9.0E-07	1.9E-12	5.0E-09	2.7E-11	2.8E-11
8B	115	377	4.3E+05	1.3E-01	3.3E-01	451900	4000	2.7E-04	4.8E-06	4.1E-08	2.5E-05	1.1E-05	0.0E+00	3.6E-07	2.7E-10	2.8E-10
8B	116	377	4.4E+05	1.3E-01	3.3E-01	455900	4000.1	2.7E-04	4.6E-06	4.2E-08	2.4E-05	1.2E-05	0.0E+00	3.3E-07	2.7E-10	2.7E-10
8B	117	377	4.4E+05	1.3E-01	3.3E-01	459900	3999.9	2.7E-04	4.5E-06	4.6E-08	2.3E-05	1.3E-05	0.0E+00	3.3E-07	2.8E-10	2.9E-10
8B	118	377	4.4E+05	1.3E-01	3.3E-01	463900	4000	2.7E-04	4.3E-06	4.9E-08	2.2E-05	1.4E-05	0.0E+00	3.1E-07	2.9E-10	2.9E-10
8B	119	377	4.4E+05	1.4E-01	3.3E-01	467900	3999.9	2.7E-04	4.2E-06	5.3E-08	2.1E-05	1.6E-05	0.0E+00	2.9E-07	3.0E-10	3.0E-10
8B	120	377	4.4E+05	1.4E-01	3.3E-01	471900	4000	2.7E-04	4.0E-06	5.9E-08	2.0E-05	1.8E-05	0.0E+00	2.7E-07	3.0E-10	3.1E-10
8B	121	820	4.0E+03	1.4E-03	4.9E-01	471900	20000	1.6E-05	1.5E-07	9.6E-09	4.8E-07	2.7E-06	2.2E-12	8.9E-09	4.9E-11	5.1E-11
8B	122	821	3.3E+03	1.2E-03	4.9E-01	471900	20000	1.3E-05	1.2E-07	7.9E-09	4.0E-07	2.2E-06	1.8E-12	7.3E-09	4.1E-11	4.2E-11
8B	123	824	1.9E+03	6.7E-04	4.9E-01	471900	20000	7.7E-06	6.9E-08	4.5E-09	2.3E-07	1.3E-06	1.0E-12	4.2E-09	2.3E-11	2.4E-11
8B	124	377	4.4E+05	1.4E-01	3.3E-01	475900	4000.2	2.7E-04	3.8E-06	6.4E-08	2.0E-05	2.0E-05	4.7E-10	2.7E-07	3.1E-10	3.2E-10
8B	125	377	4.4E+05	1.4E-01	3.3E-01	479900	3999.9	2.7E-04	3.7E-06	7.1E-08	1.9E-05	2.3E-05	0.0E+00	2.7E-07	3.2E-10	3.3E-10
8B	126	377	4.4E+05	1.4E-01	3.3E-01	483900	3999.8	2.7E-04	3.6E-06	7.9E-08	1.8E-05	2.7E-05	0.0E+00	2.6E-07	3.3E-10	3.4E-10
8B	127	377	4.4E+05	1.4E-01	3.3E-01	487900	4000.2	2.7E-04	3.4E-06	8.6E-08	1.8E-05	3.5E-05	0.0E+00	2.9E-07	3.4E-10	3.5E-10
8B	128	377	4.4E+05	1.4E-01	3.3E-01	491900	4000.1	2.7E-04	3.3E-06	9.4E-08	1.7E-05	4.8E-05	0.0E+00	3.7E-07	3.5E-10	3.6E-10
8B	129	820	4.0E+03	1.4E-03	4.8E-01	491900	20000	1.6E-05	1.1E-07	1.1E-08	3.5E-07	5.7E-06	1.5E-12	4.4E-05	4.1E-11	4.2E-11
8B	130	821	3.3E+03	1.2E-03	4.8E-01	491900	20000	1.3E-05	9.1E-08	9.3E-09	2.9E-07	4.7E-06	1.2E-12	3.6E-05	3.4E-11	3.5E-11
8B	131	824	1.9E+03	6.7E-04	4.8E-01	491900	20000	7.6E-06	5.2E-08	5.3E-09	1.7E-07	2.7E-06	6.9E-13	2.1E-05	1.9E-11	2.0E-11
8B	132	377	4.4E+05	1.4E-01	3.3E-01	495900	3999.7	2.7E-04	3.1E-06	8.9E-08	1.7E-05	7.7E-05	0.0E+00	5.7E-04	3.1E-10	3.2E-10
8B	133	379	7.1E+03	2.2E-03	3.3E-01	495900	3999.7	4.4E-06	5.0E-08	1.4E-09	2.7E-07	1.2E-06	0.0E+00	9.2E-06	5.0E-12	5.1E-12
8B	134	377	4.5E+05	1.4E-01	3.3E-01	499900	4000.2	2.7E-04	3.3E-06	1.0E-07	1.6E-05	8.8E-05	0.0E+00	8.1E-04	2.4E-10	2.4E-10
8B	135	379	7.2E+03	2.2E-03	3.3E-01	499900	3200.1	3.5E-06	4.1E-08	1.3E-09	2.1E-07	1.2E-06	0.0E+00	1.2E-05	3.0E-12	3.0E-12
8B	136	377	4.5E+05	1.4E-01	3.3E-01	503900	3999.9	2.7E-04	3.8E-06	1.1E-07	1.6E-05	3.7E-05	0.0E+00	2.4E-04	2.6E-10	2.6E-10
8B	137	377	4.5E+05	1.4E-01	3.3E-01	507900	4000	2.7E-04	4.2E-06	8.6E-08	1.5E-05	2.1E-05	0.0E+00	1.6E-04	2.1E-10	2.2E-10

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	138	377	4.5E+05	1.4E-01	3.3E-01	511900	4000.2	2.7E-04	4.5E-06	1.0E-07	1.5E-05	1.6E-05	0.0E+00	1.2E-04	2.3E-10	2.3E-10
8B	139	820	4.0E+03	1.4E-03	4.8E-01	511900	24000	1.9E-05	2.2E-07	1.4E-08	2.1E-07	2.2E-06	1.5E-12	1.9E-05	3.2E-11	3.3E-11
8B	140	821	3.3E+03	1.2E-03	4.8E-01	511900	24000	1.6E-05	1.8E-07	1.1E-08	1.7E-07	1.8E-06	1.3E-12	1.6E-05	2.7E-11	2.7E-11
8B	141	824	1.9E+03	6.7E-04	4.8E-01	511900	24000	9.0E-06	1.0E-07	6.4E-09	9.9E-08	1.0E-06	7.1E-13	9.1E-06	1.5E-11	1.6E-11
8B	142	377	4.5E+05	1.4E-01	3.3E-01	515900	3999.8	2.7E-04	4.9E-06	8.8E-08	1.4E-05	1.2E-05	0.0E+00	9.0E-05	2.1E-10	2.1E-10
8B	143	377	4.5E+05	1.4E-01	3.3E-01	519900	4000.1	2.7E-04	5.5E-06	9.3E-08	1.4E-05	1.0E-05	0.0E+00	7.3E-05	2.1E-10	2.2E-10
8B	144	377	4.5E+05	1.4E-01	3.3E-01	523900	3999.9	2.7E-04	6.0E-06	1.1E-07	1.4E-05	8.6E-06	0.0E+00	6.2E-05	2.5E-10	2.6E-10
8B	145	377	4.5E+05	1.4E-01	3.3E-01	527900	4000	2.7E-04	6.6E-06	1.1E-07	1.3E-05	7.4E-06	0.0E+00	5.3E-05	2.4E-10	2.5E-10
8B	146	377	4.5E+05	1.4E-01	3.3E-01	531900	4000	2.7E-04	7.2E-06	1.3E-07	1.3E-05	6.6E-06	0.0E+00	4.7E-05	2.8E-10	3.0E-10
8B	147	377	4.5E+05	1.4E-01	3.3E-01	535900	4000.1	2.7E-04	7.7E-06	1.4E-07	1.3E-05	5.8E-06	0.0E+00	4.2E-05	3.0E-10	3.2E-10
8B	148	820	4.1E+03	1.4E-03	4.7E-01	535900	20000	1.6E-05	3.4E-07	1.8E-08	2.2E-07	7.6E-07	2.0E-12	6.6E-06	3.8E-11	3.9E-11
8B	149	821	3.4E+03	1.2E-03	4.7E-01	535900	20000	1.3E-05	2.8E-07	1.4E-08	1.8E-07	6.3E-07	1.6E-12	5.4E-06	3.1E-11	3.2E-11
8B	150	824	1.9E+03	6.7E-04	4.7E-01	535900	20000	7.4E-06	1.6E-07	8.3E-09	1.0E-07	3.6E-07	9.4E-13	3.1E-06	1.8E-11	1.9E-11
8B	151	377	4.5E+05	1.4E-01	3.3E-01	539900	3999.9	2.7E-04	8.3E-06	1.5E-07	1.2E-05	5.3E-06	0.0E+00	3.8E-05	3.2E-10	3.3E-10
8B	152	377	4.6E+05	1.4E-01	3.3E-01	543900	4000	2.7E-04	8.9E-06	1.4E-07	1.2E-05	4.9E-06	0.0E+00	3.4E-05	3.1E-10	3.2E-10
8B	153	377	4.6E+05	1.4E-01	3.3E-01	547900	4000.1	2.7E-04	9.6E-06	1.7E-07	1.2E-05	4.5E-06	0.0E+00	3.2E-05	3.5E-10	3.7E-10
8B	154	377	4.6E+05	1.4E-01	3.3E-01	551900	4000	2.7E-04	1.0E-05	1.5E-07	1.1E-05	4.1E-06	0.0E+00	2.9E-05	3.3E-10	3.5E-10
8B	155	377	4.6E+05	1.4E-01	3.3E-01	555900	3999.8	2.7E-04	1.1E-05	1.8E-07	1.1E-05	3.8E-06	0.0E+00	2.7E-05	3.7E-10	3.9E-10
8B	156	820	4.1E+03	1.4E-03	4.7E-01	555900	24000	1.9E-05	5.9E-07	2.8E-08	3.4E-07	5.2E-07	3.2E-12	4.6E-06	6.0E-11	6.2E-11
8B	157	821	3.4E+03	1.2E-03	4.7E-01	555900	24000	1.5E-05	4.9E-07	2.3E-08	2.8E-07	4.3E-07	2.7E-12	3.8E-06	5.0E-11	5.1E-11
8B	158	824	1.9E+03	6.7E-04	4.7E-01	555900	24000	8.8E-06	2.8E-07	1.3E-08	1.6E-07	2.4E-07	1.5E-12	2.2E-06	2.8E-11	2.9E-11
8B	159	377	4.6E+05	1.4E-01	3.3E-01	559900	800.13	5.5E-05	2.2E-06	3.7E-08	2.2E-06	7.2E-07	0.0E+00	5.2E-06	7.8E-11	8.2E-11
8B	160	377	4.6E+05	1.4E-01	3.3E-01	560700	3200	2.2E-04	9.0E-06	1.5E-07	8.7E-06	2.8E-06	0.0E+00	2.0E-05	3.2E-10	3.4E-10
8B	161	377	4.6E+05	1.4E-01	3.3E-01	563900	4000.1	2.7E-04	1.2E-05	2.0E-07	1.1E-05	3.3E-06	0.0E+00	2.4E-05	4.1E-10	4.3E-10
8B	162	377	4.6E+05	1.4E-01	3.3E-01	567900	3999.9	2.7E-04	1.2E-05	2.0E-07	1.0E-05	3.1E-06	0.0E+00	2.2E-05	4.2E-10	4.5E-10
8B	163	377	4.6E+05	1.4E-01	3.3E-01	571900	4000.1	2.7E-04	1.3E-05	2.1E-07	1.0E-05	2.9E-06	0.0E+00	2.1E-05	4.4E-10	4.7E-10
8B	164	377	4.6E+05	1.4E-01	3.3E-01	575900	3999.9	2.7E-04	1.3E-05	2.2E-07	1.0E-05	2.7E-06	0.0E+00	2.0E-05	4.6E-10	4.8E-10
8B	165	377	4.6E+05	1.4E-01	3.3E-01	579900	4000	2.7E-04	1.3E-05	2.3E-07	9.7E-06	2.5E-06	0.0E+00	1.9E-05	4.7E-10	5.0E-10
8B	166	820	4.1E+03	1.4E-03	4.7E-01	579900	24000	1.8E-05	7.3E-07	3.5E-08	4.1E-07	3.1E-07	4.2E-12	2.9E-06	7.4E-11	7.6E-11

Table A.1a: MACCS Plume Segment Definition

STG	Plume Segment	MELCOR Pathway	PLHEAT (J/s)	PLMFLA (kg/s)	PLMDEN (kg/m3)	PDELAY (s)	PLUDUR (s)*	Xe	Cs	Ba	I	Te	Ru	Mo	Ce	La
8B	167	821	3.4E+03	1.2E-03	4.7E-01	579900	24000	1.5E-05	6.0E-07	2.9E-08	3.4E-07	2.6E-07	3.4E-12	2.4E-06	6.1E-11	6.3E-11
8B	168	824	1.9E+03	6.7E-04	4.7E-01	579900	24000	8.7E-06	3.4E-07	1.7E-08	1.9E-07	1.5E-07	2.0E-12	1.4E-06	3.5E-11	3.6E-11
8B	169	377	4.6E+05	1.4E-01	3.3E-01	583900	4000.1	2.7E-04	1.4E-05	2.4E-07	9.6E-06	2.4E-06	0.0E+00	1.8E-05	4.9E-10	5.2E-10
8B	170	377	4.6E+05	1.4E-01	3.3E-01	587900	4000.1	2.6E-04	1.2E-05	2.0E-07	9.6E-06	2.1E-06	0.0E+00	1.4E-05	4.2E-10	4.4E-10
8B	171	377	4.6E+05	1.4E-01	3.3E-01	591900	3999.8	2.7E-04	1.0E-05	1.8E-07	9.5E-06	1.8E-06	0.0E+00	1.1E-05	3.7E-10	3.8E-10
8B	172	377	4.6E+05	1.4E-01	3.3E-01	595900	4000	2.8E-04	1.0E-05	1.8E-07	9.5E-06	1.8E-06	0.0E+00	1.1E-05	3.7E-10	3.8E-10
8B	173	377	4.6E+05	1.4E-01	3.3E-01	599900	4000.1	2.8E-04	1.0E-05	1.7E-07	9.6E-06	1.7E-06	4.7E-10	1.1E-05	3.7E-10	3.8E-10
8BR1	1	379	2.0E+06	6.3E-01	3.3E-01	175900	4000	1.5E-04	5.2E-05	1.1E-05	5.5E-05	5.7E-05	9.1E-09	7.9E-07	1.5E-13	1.5E-13
8BR1	2	379	8.5E+05	2.8E-01	3.7E-01	179900	3150.1	9.3E-04	8.4E-05	1.1E-05	8.0E-05	8.0E-05	1.1E-07	9.9E-06	2.1E-12	2.1E-12
8BR1	3	377	4.6E+07	1.6E+01	4.1E-01	180540	3614.4	2.0E-01	8.6E-03	2.7E-04	7.7E-03	7.6E-03	7.5E-05	2.0E-03	1.2E-09	1.2E-09
8BR1	4	379	1.3E+05	4.7E-02	4.8E-01	183050	3599.8	1.6E-03	4.8E-05	2.0E-07	4.6E-05	4.6E-05	1.0E-06	1.3E-05	1.7E-11	1.7E-11
8BR1	5	377	8.7E+06	3.2E+00	5.1E-01	184150	3600.2	4.0E-02	9.2E-04	7.4E-06	9.3E-04	9.3E-04	4.0E-05	2.5E-04	6.6E-10	6.6E-10
8BR1	6	379	4.4E+04	1.6E-02	5.6E-01	186650	2450.1	1.8E-04	4.2E-07	1.5E-09	3.5E-07	3.4E-07	3.7E-09	1.1E-07	6.0E-14	6.0E-14
8BR1	7	377	2.8E+06	1.0E+00	5.6E-01	187750	4483.5	1.4E-02	1.3E-04	1.1E-06	1.1E-04	1.1E-04	5.6E-06	3.6E-05	9.2E-11	9.2E-11
8BR1	8	379	3.8E+04	1.4E-02	5.6E-01	189100	5039.1	1.0E-04	2.8E-06	2.6E-08	2.5E-06	2.5E-06	9.1E-08	7.5E-07	1.5E-12	1.5E-12
8BR1	9	377	2.4E+06	8.8E-01	5.7E-01	192230	2972.6	3.3E-03	9.9E-05	8.5E-07	1.0E-04	1.0E-04	1.1E-06	2.6E-05	1.8E-11	1.8E-11
8BR1	10	377	2.0E+06	7.5E-01	5.7E-01	195210	1893.8	1.6E-03	2.3E-05	5.1E-08	1.8E-05	1.8E-05	1.6E-07	6.2E-06	2.6E-12	2.6E-12
8BR1	11	377	2.2E+06	8.2E-01	5.7E-01	197100	4000	9.4E-03	4.7E-07	2.4E-09	4.4E-07	4.3E-07	6.6E-09	1.2E-07	1.1E-13	1.1E-13
8BR1	12	379	3.3E+04	1.2E-02	5.7E-01	197100	4000	1.4E-04	7.0E-09	3.6E-11	6.4E-09	6.3E-09	9.7E-11	1.8E-09	1.6E-15	1.6E-15
8BR1	13	377	1.3E+06	4.9E-01	5.7E-01	201100	3999.9	4.9E-03	3.3E-06	1.2E-08	2.7E-06	2.7E-06	5.2E-08	8.7E-07	8.6E-13	8.6E-13
8BR1	14	379	2.0E+04	7.3E-03	5.7E-01	201100	3999.9	7.2E-05	4.8E-08	1.8E-10	3.9E-08	3.9E-08	7.7E-10	1.3E-08	1.3E-14	1.3E-14
8BR1	15	377	1.1E+06	4.0E-01	5.8E-01	205100	4334.4	4.3E-03	1.1E-06	1.4E-08	9.6E-07	9.7E-07	8.3E-08	3.0E-07	1.4E-12	1.4E-12
8BR1	16	379	2.5E+04	9.4E-03	5.8E-01	205100	2639.2	6.2E-05	1.2E-08	1.4E-10	1.1E-08	1.0E-08	8.3E-10	3.4E-09	1.4E-14	1.4E-14
8BR1	17	377	3.2E+05	1.2E-01	5.8E-01	209430	3665.6	1.2E-03	2.3E-05	1.3E-06	2.8E-05	2.8E-05	7.7E-06	8.1E-06	1.3E-10	1.3E-10
8BR1	18	379	3.5E+04	1.3E-02	5.7E-01	212050	4134.7	1.9E-05	4.9E-07	5.9E-08	6.5E-07	6.4E-07	3.4E-07	2.3E-07	6.0E-12	6.0E-12
8BR1	19	377	3.4E+06	1.3E+00	5.7E-01	213100	3084.8	1.1E-03	1.7E-05	3.4E-06	2.5E-05	2.5E-05	2.0E-05	1.1E-05	3.5E-10	3.5E-10
8BR1	20	377	3.2E+06	1.2E+00	5.7E-01	216180	1826.8	2.6E-04	1.1E-06	3.0E-08	1.3E-06	1.3E-06	1.7E-07	3.3E-07	3.1E-12	3.1E-12

**Plume durations longer than 24 hrs (86,400 sec) produced by MELMACCS were manually set to 24 hrs (8.54E+4) in the MACCS input files*

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
size (micron)		0.153	0.285	0.531	0.989	1.84	3.43	6.38	11.9	22.1	41.2
dp (micron)		0.153	0.285	0.531	0.989	1.84	3.43	6.38	11.9	20.0	41.2
5D	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
5D	Cs	3.2E-01	1.5E-01	1.3E-02	2.2E-01	1.5E-01	9.0E-02	4.0E-02	1.2E-02	6.6E-03	2.8E-03
5D	Ba	2.5E-01	1.2E-01	1.4E-02	1.6E-01	1.6E-01	1.6E-01	8.8E-02	4.0E-02	1.5E-02	3.6E-03
5D	I	3.1E-01	1.4E-01	1.2E-02	2.5E-01	1.5E-01	7.5E-02	3.5E-02	1.2E-02	7.0E-03	2.9E-03
5D	Te	3.0E-01	1.3E-01	1.2E-02	2.6E-01	1.6E-01	7.3E-02	3.4E-02	1.2E-02	7.0E-03	2.9E-03
5D	Ru	3.3E-01	1.4E-01	1.4E-02	2.5E-01	1.5E-01	5.2E-02	3.0E-02	1.6E-02	9.9E-03	3.8E-03
5D	Mo	3.0E-01	1.4E-01	1.5E-02	2.1E-01	1.6E-01	1.0E-01	4.0E-02	1.1E-02	6.2E-03	2.6E-03
5D	Ce	2.8E-02	2.0E-02	1.1E-02	4.9E-02	1.7E-01	3.0E-01	2.3E-01	1.4E-01	4.6E-02	6.0E-03
5D	La	3.6E-02	2.4E-02	1.1E-02	5.6E-02	1.7E-01	3.0E-01	2.3E-01	1.3E-01	4.4E-02	5.6E-03
5B	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
5B	Cs	2.5E-01	1.2E-01	2.5E-02	3.9E-01	1.5E-01	3.2E-02	1.9E-02	8.3E-03	4.8E-03	2.0E-03
5B	Ba	2.6E-01	1.3E-01	4.6E-02	3.5E-01	1.3E-01	3.8E-02	2.5E-02	1.2E-02	6.2E-03	2.9E-03
5B	I	2.6E-01	1.1E-01	3.0E-02	4.0E-01	1.3E-01	3.1E-02	2.3E-02	1.0E-02	5.6E-03	2.3E-03
5B	Te	2.6E-01	1.1E-01	2.8E-02	4.0E-01	1.2E-01	3.3E-02	2.4E-02	1.0E-02	5.6E-03	2.3E-03
5B	Ru	2.7E-01	1.2E-01	3.6E-02	3.8E-01	1.1E-01	3.1E-02	2.6E-02	1.2E-02	6.6E-03	2.5E-03
5B	Mo	2.5E-01	1.1E-01	2.6E-02	3.8E-01	1.6E-01	3.5E-02	2.0E-02	8.7E-03	5.0E-03	2.1E-03
5B	Ce	2.9E-02	1.1E-02	9.4E-03	5.9E-02	1.3E-01	2.0E-01	1.7E-01	9.5E-02	4.6E-02	2.5E-01
5B	La	1.6E-01	8.0E-02	3.9E-02	2.4E-01	1.5E-01	1.2E-01	7.6E-02	3.6E-02	1.7E-02	7.5E-02
5	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
5	Cs	8.5E-02	3.4E-02	1.1E-02	2.5E-02	1.1E-01	3.9E-01	1.9E-01	1.1E-01	4.7E-02	8.0E-03
5	Ba	8.8E-02	3.9E-02	1.7E-02	3.6E-02	1.2E-01	3.3E-01	1.7E-01	9.9E-02	4.3E-02	5.9E-02
5	I	9.7E-02	3.7E-02	1.2E-02	3.4E-02	1.2E-01	3.4E-01	1.9E-01	1.2E-01	5.2E-02	8.5E-03
5	Te	1.0E-01	3.7E-02	1.2E-02	3.3E-02	1.2E-01	3.4E-01	1.8E-01	1.2E-01	5.0E-02	8.1E-03
5	Ru	1.1E-01	4.0E-02	1.3E-02	4.0E-02	1.2E-01	3.0E-01	1.9E-01	1.3E-01	5.5E-02	8.8E-03
5	Mo	1.1E-01	3.3E-02	9.0E-03	2.2E-02	9.6E-02	3.4E-01	1.8E-01	1.2E-01	6.5E-02	1.9E-02
5	Ce	2.9E-02	3.0E-02	1.5E-02	3.3E-02	8.7E-02	1.5E-01	1.8E-01	1.2E-01	5.9E-02	3.0E-01
5	La	1.2E-01	6.6E-02	2.4E-02	3.5E-02	7.7E-02	1.3E-01	1.5E-01	1.0E-01	5.4E-02	2.4E-01

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
8B	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
8B	Cs	4.0E-02	1.6E-02	1.2E-02	5.8E-02	1.9E-01	2.7E-01	2.2E-01	1.3E-01	4.5E-02	1.3E-02
8B	Ba	8.4E-02	5.6E-02	3.6E-02	7.5E-02	2.0E-01	2.4E-01	1.8E-01	9.8E-02	3.2E-02	7.4E-03
8B	I	3.6E-02	2.5E-02	1.2E-02	5.1E-02	1.9E-01	2.7E-01	2.2E-01	1.3E-01	4.6E-02	1.3E-02
8B	Te	6.8E-02	2.9E-02	1.4E-02	6.3E-02	1.9E-01	2.6E-01	2.0E-01	1.2E-01	4.1E-02	1.1E-02
8B	Ru	5.0E-02	1.1E-02	8.9E-03	5.2E-02	1.9E-01	2.8E-01	2.3E-01	1.4E-01	4.6E-02	7.9E-03
8B	Mo	3.8E-02	1.2E-02	1.2E-02	5.9E-02	2.0E-01	2.8E-01	2.2E-01	1.3E-01	4.3E-02	1.2E-02
8B	Ce	8.0E-02	2.9E-02	3.1E-02	9.3E-02	2.1E-01	2.5E-01	1.8E-01	9.2E-02	3.0E-02	5.7E-03
8B	La	7.9E-02	2.7E-02	3.1E-02	9.3E-02	2.1E-01	2.5E-01	1.8E-01	9.2E-02	3.0E-02	5.7E-03
8BR1	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
8BR1	Cs	3.1E-01	1.7E-01	5.3E-02	1.1E-01	2.1E-01	1.2E-01	2.4E-02	2.0E-03	6.2E-05	2.9E-05
8BR1	Ba	2.1E-01	3.7E-01	2.1E-01	6.2E-02	7.7E-02	5.3E-02	1.6E-02	1.9E-03	7.8E-05	2.5E-05
8BR1	I	3.1E-01	1.7E-01	6.0E-02	1.3E-01	2.0E-01	1.0E-01	2.1E-02	1.9E-03	6.5E-05	2.7E-05
8BR1	Te	3.1E-01	1.7E-01	6.0E-02	1.3E-01	2.0E-01	1.0E-01	2.1E-02	1.9E-03	6.5E-05	1.7E-05
8BR1	Ru	2.8E-01	6.2E-02	9.4E-02	3.1E-01	1.9E-01	4.3E-02	6.6E-03	7.3E-04	3.1E-05	2.4E-06
8BR1	Mo	3.2E-01	1.4E-01	3.2E-02	1.3E-01	2.3E-01	1.3E-01	2.4E-02	2.0E-03	5.8E-05	1.7E-05
8BR1	Ce	2.8E-01	6.4E-02	9.6E-02	3.1E-01	1.9E-01	4.4E-02	6.8E-03	7.5E-04	3.2E-05	4.1E-06
8BR1	La	2.8E-01	6.4E-02	9.6E-02	3.1E-01	1.9E-01	4.4E-02	6.8E-03	7.5E-04	3.2E-05	4.1E-06
8	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
8	Cs	2.4E-02	8.5E-03	4.6E-03	3.0E-02	1.2E-01	2.4E-01	2.8E-01	2.0E-01	7.6E-02	1.9E-02
8	Ba	1.3E-01	2.9E-02	2.4E-03	3.5E-02	1.4E-01	2.5E-01	2.3E-01	1.3E-01	3.9E-02	8.0E-03
8	I	2.7E-02	2.3E-02	2.0E-02	3.9E-02	1.2E-01	2.3E-01	2.6E-01	1.9E-01	7.2E-02	1.9E-02
8	Te	2.4E-02	5.4E-03	1.1E-03	2.7E-02	1.2E-01	2.4E-01	2.8E-01	2.1E-01	7.9E-02	2.0E-02
8	Ru	1.5E-02	2.9E-03	1.1E-03	2.4E-02	1.0E-01	2.3E-01	2.8E-01	2.3E-01	9.0E-02	2.6E-02
8	Mo	1.4E-02	4.2E-03	5.0E-03	3.5E-02	1.3E-01	2.5E-01	2.7E-01	2.0E-01	7.3E-02	1.8E-02
8	Ce	3.3E-02	1.1E-02	1.4E-02	5.8E-02	1.4E-01	1.9E-01	2.1E-01	1.7E-01	1.0E-01	6.0E-02
8	La	2.3E-02	3.5E-02	4.9E-02	9.9E-02	2.1E-01	2.4E-01	1.8E-01	1.1E-01	4.6E-02	1.9E-02
3A2	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
3A2	Cs	6.8E-03	3.7E-03	1.4E-02	6.1E-02	1.6E-01	2.4E-01	2.3E-01	1.7E-01	8.3E-02	3.0E-02

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
3A2	Ba	1.2E-02	6.2E-03	2.9E-02	1.3E-01	2.6E-01	2.9E-01	1.7E-01	6.9E-02	2.4E-02	7.4E-03
3A2	I	9.5E-03	4.0E-03	1.9E-02	7.4E-02	1.7E-01	2.5E-01	2.3E-01	1.5E-01	6.5E-02	2.2E-02
3A2	Te	5.0E-03	2.1E-03	1.4E-02	9.0E-02	2.5E-01	2.7E-01	1.8E-01	1.2E-01	5.4E-02	1.9E-02
3A2	Ru	7.4E-03	2.5E-03	5.4E-03	3.2E-02	1.3E-01	2.3E-01	2.6E-01	2.1E-01	9.7E-02	3.2E-02
3A2	Mo	7.0E-03	7.9E-03	3.1E-02	7.8E-02	1.8E-01	2.4E-01	2.1E-01	1.5E-01	7.2E-02	2.7E-02
3A2	Ce	2.8E-02	3.8E-02	8.0E-02	1.7E-01	2.8E-01	2.5E-01	1.1E-01	3.0E-02	1.0E-02	3.0E-03
3A2	La	1.0E-02	2.4E-02	8.4E-02	1.8E-01	2.9E-01	2.6E-01	1.1E-01	3.1E-02	1.1E-02	3.2E-03
7	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
7	Cs	1.2E-01	1.9E-02	1.9E-02	7.6E-02	1.6E-01	1.8E-01	1.6E-01	1.3E-01	7.9E-02	4.4E-02
7	Ba	4.6E-02	1.5E-02	2.7E-02	1.2E-01	2.4E-01	2.2E-01	1.4E-01	9.8E-02	5.7E-02	3.8E-02
7	I	1.1E-01	2.1E-02	1.9E-02	7.7E-02	1.7E-01	1.9E-01	1.6E-01	1.3E-01	7.8E-02	4.5E-02
7	Te	1.2E-01	2.2E-02	1.8E-02	8.0E-02	1.7E-01	1.7E-01	1.5E-01	1.3E-01	8.3E-02	4.9E-02
7	Ru	1.1E-01	1.6E-02	1.9E-03	3.8E-02	1.0E-01	1.6E-01	1.8E-01	1.9E-01	1.3E-01	7.8E-02
7	Mo	1.6E-02	9.6E-03	2.2E-02	6.2E-02	1.6E-01	2.3E-01	2.3E-01	1.8E-01	7.8E-02	2.2E-02
7	Ce	5.0E-02	8.8E-03	7.5E-03	1.0E-01	2.2E-01	2.3E-01	1.6E-01	1.1E-01	6.4E-02	4.7E-02
7	La	3.0E-02	1.4E-02	3.0E-02	1.3E-01	2.5E-01	2.4E-01	1.5E-01	8.6E-02	4.4E-02	3.0E-02
7A	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
7A	Cs	1.6E-01	2.3E-02	1.4E-02	6.8E-02	1.5E-01	1.7E-01	1.5E-01	1.4E-01	8.2E-02	4.9E-02
7A	Ba	7.9E-02	2.6E-02	4.0E-02	1.4E-01	2.7E-01	2.2E-01	1.0E-01	6.4E-02	3.8E-02	2.2E-02
7A	I	1.4E-01	2.4E-02	1.6E-02	7.0E-02	1.5E-01	1.7E-01	1.5E-01	1.4E-01	8.5E-02	4.9E-02
7A	Te	1.7E-01	2.3E-02	4.5E-03	4.4E-02	1.1E-01	1.6E-01	1.6E-01	1.6E-01	1.0E-01	6.0E-02
7A	Ru	1.2E-01	1.7E-02	7.7E-04	3.1E-02	9.2E-02	1.5E-01	1.8E-01	2.0E-01	1.4E-01	8.1E-02
7A	Mo	1.5E-02	9.8E-03	2.2E-02	6.0E-02	1.5E-01	2.2E-01	2.2E-01	1.8E-01	9.1E-02	2.8E-02
7A	Ce	1.8E-01	2.9E-02	5.9E-03	1.8E-01	3.5E-01	2.3E-01	3.2E-02	4.0E-03	8.4E-04	2.7E-04
7A	La	4.5E-02	2.7E-02	5.5E-02	1.8E-01	3.3E-01	2.4E-01	8.5E-02	2.2E-02	5.6E-03	1.6E-03
2A	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
2A	Cs	3.4E-02	2.2E-03	1.7E-02	1.4E-01	2.7E-01	2.7E-01	1.7E-01	7.0E-02	1.4E-02	1.1E-03
2A	Ba	3.2E-02	2.7E-03	2.3E-02	1.4E-01	2.9E-01	2.8E-01	1.6E-01	6.0E-02	1.1E-02	9.1E-04
2A	I	2.8E-02	1.3E-03	1.8E-02	1.3E-01	2.7E-01	2.8E-01	1.9E-01	7.5E-02	1.4E-02	1.0E-03

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
2A	Te	4.3E-02	1.6E-03	1.5E-02	1.3E-01	2.7E-01	3.0E-01	1.7E-01	5.9E-02	1.1E-02	7.9E-04
2A	Ru	3.4E-02	2.0E-03	1.8E-02	1.4E-01	2.7E-01	2.9E-01	1.8E-01	6.6E-02	1.2E-02	9.2E-04
2A	Mo	2.4E-02	8.2E-04	8.3E-03	6.5E-02	1.7E-01	3.1E-01	2.6E-01	1.3E-01	2.9E-02	2.0E-03
2A	Ce	3.2E-02	2.2E-03	2.7E-02	1.4E-01	2.9E-01	2.8E-01	1.6E-01	5.7E-02	1.0E-02	1.0E-03
2A	La	3.9E-02	2.9E-03	3.1E-02	1.5E-01	3.1E-01	2.8E-01	1.3E-01	4.3E-02	6.5E-03	5.8E-04
1B	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
1B	Cs	8.6E-03	2.6E-02	7.1E-02	1.8E-01	3.3E-01	2.7E-01	9.5E-02	1.0E-02	9.7E-04	5.1E-04
1B	Ba	1.0E-02	2.3E-02	6.9E-02	1.8E-01	3.1E-01	2.7E-01	1.1E-01	2.2E-02	2.9E-03	9.4E-04
1B	I	1.1E-02	2.7E-02	7.8E-02	2.0E-01	3.4E-01	2.5E-01	7.4E-02	9.1E-03	1.4E-03	5.5E-04
1B	Te	2.4E-02	1.3E-02	5.5E-02	1.4E-01	2.5E-01	2.4E-01	1.7E-01	8.3E-02	2.3E-02	3.3E-03
1B	Ru	3.8E-02	2.8E-02	5.9E-02	1.5E-01	2.7E-01	2.6E-01	1.4E-01	3.5E-02	8.8E-03	6.2E-03
1B	Mo	1.0E-02	4.5E-03	3.1E-02	8.5E-02	1.9E-01	2.5E-01	2.3E-01	1.4E-01	4.6E-02	6.9E-03
1B	Ce	1.0E-02	2.6E-02	7.6E-02	2.0E-01	3.3E-01	2.4E-01	8.8E-02	1.7E-02	4.1E-03	3.3E-03
1B	La	1.1E-02	2.4E-02	7.2E-02	1.8E-01	3.2E-01	2.7E-01	1.0E-01	1.6E-02	2.2E-03	5.4E-04
2R2	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
2R2	Cs	2.1E-02	5.7E-02	9.7E-02	2.1E-01	2.7E-01	2.3E-01	1.0E-01	2.0E-02	1.9E-03	1.5E-04
2R2	Ba	1.3E-02	4.2E-02	9.2E-02	1.9E-01	3.1E-01	2.6E-01	8.1E-02	8.1E-03	4.2E-04	2.7E-05
2R2	I	2.1E-02	4.5E-02	7.6E-02	1.6E-01	2.8E-01	2.8E-01	1.2E-01	2.2E-02	2.4E-03	3.3E-04
2R2	Te	1.1E-02	3.0E-02	7.2E-02	1.7E-01	3.1E-01	2.8E-01	1.0E-01	2.3E-02	4.7E-03	6.4E-04
2R2	Ru	2.4E-02	6.5E-03	8.0E-03	6.4E-02	2.0E-01	3.2E-01	2.6E-01	1.0E-01	1.6E-02	2.4E-03
2R2	Mo	1.3E-02	4.0E-02	8.5E-02	1.8E-01	3.0E-01	2.6E-01	9.6E-02	2.0E-02	3.6E-03	3.9E-04
2R2	Ce	2.0E-02	5.1E-02	8.4E-02	1.7E-01	2.8E-01	2.8E-01	1.1E-01	1.6E-02	9.1E-04	3.7E-05
2R2	La	1.5E-02	4.6E-02	9.3E-02	1.9E-01	3.0E-01	2.6E-01	8.7E-02	1.1E-02	6.0E-04	2.6E-05
1A2	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
1A2	Cs	3.0E-02	7.4E-03	7.7E-02	2.7E-01	3.4E-01	1.6E-01	7.5E-02	3.8E-02	9.1E-03	6.1E-04
1A2	Ba	3.2E-02	6.9E-03	7.4E-02	2.6E-01	3.5E-01	1.7E-01	6.6E-02	2.5E-02	5.1E-03	3.5E-04
1A2	I	3.9E-02	4.6E-03	6.9E-02	2.8E-01	3.7E-01	1.5E-01	6.1E-02	2.5E-02	5.8E-03	4.4E-04
1A2	Te	4.6E-02	1.9E-03	5.5E-02	2.2E-01	3.6E-01	2.2E-01	7.3E-02	1.9E-02	3.4E-03	3.3E-04
1A2	Ru	1.6E-02	1.2E-02	7.2E-02	2.0E-01	2.6E-01	1.9E-01	1.4E-01	8.9E-02	2.7E-02	3.8E-03

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
1A2	Mo	8.0E-03	6.9E-04	1.2E-02	5.1E-02	1.7E-01	3.3E-01	2.7E-01	1.3E-01	2.5E-02	1.7E-03
1A2	Ce	1.5E-02	1.2E-02	7.8E-02	2.2E-01	2.7E-01	1.7E-01	1.2E-01	8.3E-02	2.5E-02	2.0E-03
1A2	La	3.3E-02	6.5E-03	6.6E-02	2.4E-01	3.5E-01	1.9E-01	7.7E-02	3.0E-02	7.0E-03	5.1E-04
1A2_TR28	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
1A2_TR28	Cs	2.2E-01	4.6E-02	3.9E-03	1.9E-02	6.6E-02	1.1E-01	1.7E-01	1.8E-01	1.2E-01	6.5E-02
1A2_TR28	Ba	7.2E-02	1.3E-02	7.4E-03	4.7E-02	1.2E-01	1.6E-01	2.0E-01	1.8E-01	1.2E-01	8.3E-02
1A2_TR28	I	2.0E-01	4.0E-02	3.9E-03	2.1E-02	7.2E-02	1.2E-01	1.7E-01	1.8E-01	1.2E-01	6.9E-02
1A2_TR28	Te	2.0E-01	4.1E-02	4.2E-03	2.1E-02	7.2E-02	1.2E-01	1.7E-01	1.8E-01	1.2E-01	6.8E-02
1A2_TR28	Ru	1.6E-01	2.8E-02	9.4E-04	1.1E-02	4.9E-02	1.0E-01	1.9E-01	2.2E-01	1.5E-01	8.7E-02
1A2_TR28	Mo	1.2E-01	2.6E-02	6.6E-03	2.6E-02	1.0E-01	2.0E-01	2.1E-01	1.8E-01	9.0E-02	3.9E-02
1A2_TR28	Ce	3.6E-02	4.0E-03	2.9E-03	3.9E-02	1.1E-01	1.7E-01	2.3E-01	1.9E-01	1.3E-01	9.7E-02
1A2_TR28	La	3.2E-02	4.4E-03	7.8E-03	5.3E-02	1.4E-01	1.8E-01	2.1E-01	1.8E-01	1.1E-01	8.6E-02
6	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
6	Cs	6.5E-02	1.2E-01	8.3E-02	1.5E-01	2.1E-01	1.6E-01	8.9E-02	5.0E-02	2.9E-02	5.8E-02
6	Ba	1.4E-01	1.5E-01	9.4E-02	1.3E-01	1.6E-01	1.3E-01	8.4E-02	4.7E-02	3.0E-02	3.3E-02
6	I	7.0E-02	1.2E-01	7.8E-02	1.3E-01	1.9E-01	1.6E-01	9.7E-02	5.7E-02	3.5E-02	6.5E-02
6	Te	8.9E-02	1.4E-01	1.1E-01	1.6E-01	1.9E-01	1.3E-01	7.4E-02	4.0E-02	2.3E-02	4.2E-02
6	Ru	7.6E-02	1.2E-01	4.8E-02	6.3E-02	1.2E-01	1.5E-01	1.3E-01	9.9E-02	6.4E-02	1.3E-01
6	Mo	1.1E-01	1.7E-01	1.8E-01	2.2E-01	1.9E-01	9.2E-02	3.3E-02	1.0E-02	2.8E-03	1.6E-03
6	Ce	7.4E-02	1.2E-01	5.5E-02	8.8E-02	1.6E-01	1.8E-01	1.4E-01	8.1E-02	5.2E-02	5.2E-02
6	La	1.8E-01	1.6E-01	1.2E-01	1.5E-01	1.6E-01	1.1E-01	5.6E-02	2.7E-02	1.5E-02	1.4E-02
2R1	Xe	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01
2R1	Cs	8.0E-02	5.1E-02	1.3E-02	4.5E-02	1.5E-01	2.1E-01	1.9E-01	1.3E-01	7.2E-02	7.2E-02
2R1	Ba	3.9E-02	2.7E-02	2.9E-02	9.4E-02	2.1E-01	2.4E-01	1.8E-01	1.0E-01	4.7E-02	3.6E-02
2R1	I	4.6E-02	3.0E-02	2.2E-02	7.6E-02	1.8E-01	2.3E-01	1.9E-01	1.2E-01	5.7E-02	4.4E-02
2R1	Te	4.7E-02	3.2E-02	2.3E-02	7.4E-02	1.8E-01	2.3E-01	1.9E-01	1.2E-01	6.0E-02	4.3E-02
2R1	Ru	6.4E-02	2.4E-02	4.1E-03	3.5E-02	1.1E-01	1.7E-01	2.0E-01	1.7E-01	1.1E-01	1.1E-01
2R1	Mo	8.1E-03	9.7E-03	2.0E-02	6.1E-02	1.5E-01	2.2E-01	2.2E-01	1.8E-01	9.4E-02	3.7E-02
2R1	Ce	5.4E-02	2.1E-02	6.7E-03	2.5E-02	9.3E-02	1.7E-01	1.8E-01	1.7E-01	1.1E-01	1.8E-01

Table A.1b: Chemical Group Release Fraction by Particle-Size Distribution

ST	Group	1	2	3	4	5	6	7	8	9	10
2R1	La	5.2E-02	2.1E-02	7.3E-03	2.5E-02	9.4E-02	1.7E-01	1.8E-01	1.7E-01	1.0E-01	1.8E-01

Table A.2a: EP Model 1/1S: 10-Mile Evacuation Population Distribution Fractions

	EP Model 1S: Schools Cohort, 10-mile evacuation						EP Model 1:No Schools Cohort, 10-mile evacuation					
	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND
LBL	1	2	3	4	5	6	1	2	3	4	5	6
1GP1	0.2985						0.2985					
1GP2	0.2985						0.2985					
1GP3	0.2985						0.2985					
1GPT	0.0995						0.0995					
IND						1						1
1GPS		0.105332913						0.2				
2GP1												
2GP2												
2GP3												
2GPT												
SCH		0.473335437										
2GPS												
3GP1												
3GP2												
3GP3												
3GPT												
3GPS												
NE	0.005	0.42133165	1	1	1		0.005	0.8	1	1	1	
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table A.2b: EP Model 2/2S: 15-Mile Evacuation Population Distribution Fractions

	EP Model 2S: Schools Cohort, 15-mile evacuation						EP Model 2:No Schools Cohort, 15-mile evacuation					
	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND
LBL	1	2	3	4	5	6	1	2	3	4	5	6
1GP1	0.2985						0.2985					
1GP2	0.2985						0.2985					
1GP3	0.2985						0.2985					
1GPT	0.0995						0.0995					
IND						1						1
1GPS		0.105332913						0.2				
2GP1		0.125767498						0.2388				
2GP2		0.125767498						0.2388				
2GP3		0.125767498						0.2388				
2GPT		0.041922499						0.0796				
SCH		0.473335437										
2GPS			0.2						0.2			
3GP1												
3GP2												
3GP3												
3GPT												
3GPS												
NE	0.005	0.002106658	0.8	1	1		0.005	0.004	0.8	1	1	
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table A.2c: EP Model 3/3S: 20-Mile Evacuation Population Distribution Fractions

	EP Model 3S: Schools Cohort, 20-mile evacuation						EP Model 3:No Schools Cohort, 20-mile evacuation					
	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND	0–10 GP	10-15 GP	15-20 GP	20-25 GP	>25 GP	IND
LBL	1	2	3	4	5	6	1	2	3	4	5	6
1GP1	0.2985						0.2985					
1GP2	0.2985						0.2985					
1GP3	0.2985						0.2985					
1GPT	0.0995						0.0995					
IND						1						1
1GPS		0.105332913						0.2				
2GP1		0.125767498						0.2388				
2GP2		0.125767498						0.2388				
2GP3		0.125767498						0.2388				
2GPT		0.041922499						0.0796				
SCH		0.473335437										
2GPS												
3GP1			0.2985						0.2985			
3GP2			0.2985						0.2985			
3GP3			0.2985						0.2985			
3GPT			0.0995						0.0995			
3GPS				0.2						0.2		
NE	0.005	0.002106658	0.005	0.8	1		0.005	0.004	0.005	0.8	1	
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table A.3: Speed Multipliers for Network Evacuation (ESPGRD_NET)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table A.3: Speed Multipliers for Network Evacuation (ESPGRD_NET)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
36	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
38	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
46	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
48	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
51	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
52	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
53	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
54	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1

Table A.3: Speed Multipliers for Network Evacuation (ESPGRD_NET)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
55	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
56	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
57	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
59	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
61	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
62	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.80	0.80	0.80	1	1
63	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
64	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table A.4: Evacuation Network (IDIREC)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	1	2	2	4	1	1	4	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	2	2	2	1	1	1	1	1	1	1	1	4	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	2	2	2	1	1	1	1	1	4	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	2	2	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	2	2	2	1	1	1	1	4	1	1	4	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	2	2	2	1	1	1	1	4	1	1	4	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	2	2	2	1	1	1	1	4	1	1	4	1	2	4	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	2	2	2	1	1	1	1	1	1	1	4	1	1	4	1	1	1	4	1	1	1	1	1	1	1	1	1
9	1	2	2	2	1	1	1	4	1	1	1	2	1	4	4	1	1	1	4	1	4	1	1	1	1	1	1	1
10	1	2	2	2	1	1	1	4	1	1	1	2	1	4	4	1	1	1	4	1	4	1	1	1	1	1	1	1
11	1	2	2	2	1	1	1	4	1	1	1	2	1	4	4	1	1	1	4	1	2	1	1	1	1	1	1	1
12	1	2	2	2	1	1	1	4	1	2	1	2	1	4	4	1	1	2	2	1	2	1	1	1	1	1	1	1
13	1	2	2	2	1	1	1	4	2	2	1	2	1	2	4	1	1	2	2	1	1	1	1	1	1	1	1	1
14	1	2	2	2	1	1	1	1	2	2	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	2	2	2	1	1	1	1	1	2	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	2	2	2	1	1	1	1	1	1	4	1	1	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	2	2	2	1	1	1	1	4	4	4	1	1	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	2	2	2	2	1	1	1	4	4	4	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	2	1	2	2	1	1	1	4	4	4	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1
20	1	2	1	2	2	2	1	1	1	4	4	1	1	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
21	1	2	4	2	2	2	1	1	1	1	4	4	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	2	4	2	1	2	2	2	1	1	4	4	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	1	2	4	2	2	1	2	2	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	4	1	1	1	1
24	1	2	4	2	2	4	1	2	1	1	1	1	2	2	4	1	1	1	1	1	1	1	2	1	1	1	1	1
25	1	1	1	2	2	4	4	2	1	1	1	1	2	2	1	1	1	4	1	1	1	2	2	1	1	1	1	1
26	1	1	2	2	2	4	4	2	1	1	1	1	1	2	2	1	1	4	1	1	1	2	1	1	1	1	1	1
27	1	1	2	2	2	4	4	2	2	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1

Table A.4: Evacuation Network (IDIREC)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
28	1	1	2	2	2	4	2	1	2	2	1	1	4	2	2	1	1	1	1	1	1	1	2	1	1	1	1	1
29	1	1	2	2	2	2	2	1	2	2	1	1	2	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1
30	1	1	2	2	2	2	2	2	1	2	2	1	2	1	4	1	1	4	1	1	1	1	1	1	1	1	1	1
31	1	1	2	1	2	2	2	2	1	2	2	1	1	1	4	1	1	2	1	1	1	1	1	1	1	1	1	1
32	1	1	2	1	2	2	2	2	1	1	2	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1
33	1	1	2	1	2	2	2	1	1	1	2	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1
34	1	4	2	1	2	2	2	1	1	1	2	1	1	4	1	1	1	4	1	1	1	1	1	1	1	1	1	1
35	1	4	2	1	2	2	1	4	1	1	2	1	1	4	2	1	1	4	1	1	1	1	1	1	1	1	1	1
36	1	4	1	1	2	1	1	4	2	2	2	1	1	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
37	1	4	4	1	2	4	4	4	2	2	2	1	1	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1
38	1	4	4	1	1	4	2	4	2	2	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1
39	1	4	4	2	2	4	1	4	2	1	1	1	2	2	2	1	1	1	1	1	1	1	4	1	1	1	1	1
40	1	4	4	2	2	4	2	4	2	1	4	4	2	2	2	1	1	1	1	1	1	4	1	1	1	1	1	1
41	1	4	4	2	2	4	2	4	1	2	4	4	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
42	1	4	4	2	1	1	2	4	1	1	2	2	2	2	1	2	1	1	1	1	4	1	1	1	1	1	1	1
43	1	4	4	2	4	4	1	1	1	1	2	2	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1
44	1	4	4	2	4	4	4	1	1	4	1	1	4	2	4	1	1	2	1	1	1	1	1	1	1	1	1	1
45	1	4	4	2	4	2	2	1	2	4	1	1	4	2	4	4	4	1	1	1	4	1	1	1	1	1	1	1
46	1	4	4	2	4	2	2	1	2	4	1	1	2	2	4	4	4	4	1	1	4	1	1	1	1	1	1	1
47	1	4	4	2	4	2	1	1	2	4	1	1	2	2	4	4	1	4	1	1	2	1	1	1	1	1	1	1
48	1	4	4	2	4	1	1	1	1	2	1	4	1	2	4	1	1	1	1	1	2	1	1	1	1	1	1	1
49	1	4	4	2	1	2	1	1	4	1	1	4	4	1	4	1	1	1	1	1	2	1	1	1	1	1	1	1
50	1	4	4	2	1	2	1	1	4	1	4	4	4	4	1	1	1	1	1	1	2	1	1	1	1	1	1	1
51	1	4	4	1	2	1	4	1	4	4	4	4	4	4	1	1	2	1	1	1	2	1	1	1	1	1	1	1
52	1	4	4	4	2	1	4	1	4	4	4	4	1	4	1	1	2	1	1	1	2	1	1	1	1	1	1	1
53	1	4	4	4	2	4	2	1	4	4	4	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1
54	1	4	4	4	2	4	2	1	4	4	1	1	2	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1

Table A.4: Evacuation Network (IDIREC)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
55	1	4	4	4	1	4	1	1	1	4	1	1	2	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1
56	1	4	4	4	1	4	1	1	1	4	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
57	1	4	4	4	4	4	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
58	1	4	4	4	4	4	4	1	1	1	1	1	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
59	1	4	4	4	4	4	4	1	1	1	1	1	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
60	1	4	4	4	4	4	4	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
61	1	4	4	4	4	4	4	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
62	1	4	4	4	4	4	4	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
63	1	4	4	4	4	4	4	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
64	1	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table B.1a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4566
2	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3531
3	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3111
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3111
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2426
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2253
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2227
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2221
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD-CENTERED)	0.1713
10	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1677
11	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1605
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1550
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1494
14	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1448
15	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1447
16	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1320
17	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1297
18	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1235
19	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1216
20	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1118
21	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1093
22	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1084
23	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.1002

Table B.1a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–50 Miles)			
	Basic Event	Description	Composite FV
24	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0859
25	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0793
26	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0782
27	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0732
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0720
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0711
30	1-IE-LONSCW	LOSS OF NSCW	0.0705
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0682
32	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0546
33	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0530
34	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0520
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0513
36	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0477
37	1-IE-OTRANS	OTHER TRANSIENT	0.0474
38	1-IE-MLOCA	MEDIUM LOCA	0.0466
39	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0465
40	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0419
41	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0390
42	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0361
43	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0339
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0328
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT- CENTERED)	0.0311
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0308

Table B.1a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–50 Miles)			
	Basic Event	Description	Composite FV
47	1-DCP-BAT-MA-BD1B_____	BATTERY 1BD1B IN MAINTENANCE	0.0262
48	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0262
49	1-DCP-BAT-MA-AD1B_____	BATTERY 1AD1B IN MAINTENANCE	0.0258
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0221
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0217
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0209
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0209
54	1-IE-TTRIP	TURBINE TRIP	0.0196
55	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0194
56	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0189
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0182
58	1-DCP-BDC-FC-BD1&_____	125V BUS 1BD1 FAILS (1YR)	0.0182
59	1-IE-RTRIP	REACTOR TRIP	0.0179
60	1-ACP-BAC-MA-AA02_____	BUS 1AA02 IN MAINTENANCE	0.0175
61	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0157
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0156
63	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0155
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0143
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0133
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0129
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0121
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0117
69	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0098
70	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0094
71	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0088

Table B.1a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
72	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0085
73	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0083
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0081
75	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0079
76	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0073
77	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0072
78	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0072
79	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0062
80	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0062
81	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0059
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0057
83	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0057
84	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0056
85	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0056
86	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0056
87	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0052

Table B.1b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4550
2	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3483
3	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3238
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3092
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2413
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2259
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2241
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2234
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD-CENTERED)	0.1704
10	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1673
11	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1597
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1540
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1501
14	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1453
15	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1428
16	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1402
17	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1292
18	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1291
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1228
20	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1106
21	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1087
22	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1081
23	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0995

Table B.1b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
24	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0853
25	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0790
26	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0776
27	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0739
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0716
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0707
30	1-IE-LONSCW	LOSS OF NSCW	0.0697
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0673
32	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0539
33	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0527
34	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0517
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0516
36	1-IE-MLOCA	MEDIUM LOCA	0.0489
37	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0474
38	1-IE-OTRANS	OTHER TRANSIENT	0.0472
39	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0462
40	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0444
41	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0394
42	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0387
43	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0383
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0326
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0310
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0306
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0261
48	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0258
49	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0257
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0220
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0216

Table B.1b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–100 Miles)			
	Basic Event	Description	Composite FV
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0209
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0207
54	1-IE-TTRIP	TURBINE TRIP	0.0195
55	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0192
56	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0188
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0181
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0181
59	1-IE-RTRIP	REACTOR TRIP	0.0178
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0174
61	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0155
62	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0155
63	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0155
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0143
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0134
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0128
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0119
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0116
69	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0101
70	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0097
71	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0093
72	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0089
73	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0084
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0082
75	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0079
76	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0074
77	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0074
78	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0072
79	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0062

Table B.1b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Dose (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
80	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0061
81	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0058
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0057
83	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0057
84	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0056
85	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0056
86	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0056
87	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0052
88	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0052

Table B.2: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Early Fatality Risk (0–1.8 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.6013
2	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.5624
3	1-IE-ISL-RHR-CLI-A	RHR COLD LEG INJECTION TRAIN A ISOLATION	0.1109
4	1-IE-ISL-RHR-CLI-B	RHR COLD LEG INJECTION TRAIN B ISOLATION	0.1109
5	1-IE-RHR-MOV-RP-HV8701B	RHR SUCTION MOV HV8701B (ISLOCA INITIATOR)	0.1034
6	1-IE-RHR-MOV-RP-HV8702B	RHR SUCTION MOV HV8702B (ISLOCA INITIATOR)	0.1034
7	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0980
8	1-RHR-MOV-RP-HV8701A-CON	RHR SUCTION MOV HV8701A FAILS (CONDITIONAL)	0.0956
9	1-RHR-MOV-RP-HV8702A-CON	RHR SUCTION MOV HV8702A FAILS (CONDITIONAL)	0.0956
10	1-IE-RHR-MOV-CO-HV8701A	RHR SUCTION MOV HV8701A TRANSFERS OPEN (ISLOCA INITIATOR)	0.0947
11	1-IE-RHR-MOV-CO-HV8701B	RHR SUCTION MOV HV8701B TRANSFERS OPEN (ISLOCA INITIATOR)	0.0947
12	1-IE-RHR-MOV-CO-HV8702A	RHR SUCTION MOV HV8702A TRANSFERS OPEN (ISLOCA INITIATOR)	0.0947
13	1-IE-RHR-MOV-CO-HV8702B	RHR SUCTION MOV HV8702B TRANSFERS OPEN (ISLOCA INITIATOR)	0.0947
14	1-RHR-MOV-CO-HV8701A_	RHR SUCTION MOV HV8701A TRANSFERS OPEN	0.0947
15	1-RHR-MOV-CO-HV8701B_	RHR SUCTION MOV HV8701A TRANSFERS OPEN	0.0947
16	1-RHR-MOV-CO-HV8702A_	RHR SUCTION MOV HV8702A TRANSFERS OPEN	0.0947
17	1-RHR-MOV-CO-HV8702B_	RHR SUCTION MOV HV8702B TRANSFERS OPEN	0.0947
18	1-RHR-MOV-OO-HV8809A-HDP	LP CL INJ MOV HV8809A FAILS TO CLOSE WITH HIGH DIFFERENTIAL PRESSURE	0.0852
19	1-RHR-MOV-OO-HV8809B-HDP	LP CL INJ MOV HV8809B FAILS TO CLOSE WITH HIGH DIFFERENTIAL PRESSUIRE	0.0852
20	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0643
21	1-IE-ISL-RCP-S1LO	RCP STAGE 1 SEAL ISOLATION	0.0632

Table B.2: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Early Fatality Risk (0–1.8 Miles)

	Basic Event	Description	Composite FV
22	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.0607
23	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.0602
24	1-IE-HPI-CKV-RP-083_____	ECCS CL1 INJ CV083 Rupture (ISLOCA INI>)	0.0554
25	1-IE-HPI-CKV-RP-084_____	ECCS CL 2 INJ CV 084 Rupture (ISLOCA INI)	0.0554
26	1-IE-HPI-CKV-RP-085_____	ECCS CL 3 INJ CV 085 Rupture (ISLOCA INI)	0.0554
27	1-IE-HPI-CKV-RP-086_____	ECCS CL4 INJ CV 086 Rupture (ISLOCA INI)	0.0554
28	1-RHR-CKV-RP-147__CON	RHR CL 1 INJ CV 147 Fails (Conditional)	0.0554
29	1-RHR-CKV-RP-148__CON	RHR CL 2 INJ CV 148 fails (Conditional)	0.0554
30	1-RHR-CKV-RP-149__CON	RHR CL 3 INJ CV 149 fails (Conditional)	0.0554
31	1-RHR-CKV-RP-150__CON	RHR CL 4 INJ CV 150 fails (Conditional)	0.0554
32	1-L2-BE-ISLOCASUBM-SM	ISLOCA Break Not Submerged or Significantly Scrubbed for Small ISLOCAs	0.0532
33	1-OA-IS-ISLRHR-H	OPERATOR FAILS TO ISOLATE ISLOCA THROUGH RHR COLD LEG INJECTION LINES	0.0481
34	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.0470
35	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.0395
36	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.0393
37	1-L2-BE-ABFH2-FANS	Aux Bldg Failure due to Combustion (Ventilation)	0.0364
38	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.0294
39	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.0275
40	1-L2-BE-ABFANS-IND-FAIL	Independent or Induced Failure of Aux Bldg Ventilation	0.0268
41	1-L2-BE-ABFH2-NOFANS	Aux Bldg Failure due to Combustion (No Ventilation)	0.0256
42	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.0251

Table B.2: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Early Fatality Risk (0–1.8 Miles)			
	Basic Event	**Description**	**Composite FV**
43	1-OA-IS-ISLSEALSBO	OPERATOR FAILS TO ISOLATE RCP SEAL LINES at LOCAL -ISLOCA w SBO	0.0244
44	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.0229
45	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0157
46	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0133
47	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0126
48	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0119
49	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0114
50	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0107
51	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0101
52	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0098
53	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0090
54	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0080
55	1-ACP-BAC-MA-MCCBBB__	480V MCC 1BBB IN MAINTENANCE	0.0080
56	1-L2-OP-SCG1-3	Operator Fails to Carry Out SCG-1 (F&B SGs - Late)	0.0079
57	1-IE-RHR-MOV-RP-HV8701A	RHR SUCTION MOV HV8701A (ISLOCA INITIATOR)	0.0078
58	1-IE-RHR-MOV-RP-HV8702A	RHR SUCTION MOV HV8702A (ISLOCA INITIATOR)	0.0078
59	1-RHR-MOV-RP-HV8701A-RAN	RHR SUCTION MOV HV8701A FAILS (RANDOM)	0.0078
60	1-RHR-MOV-RP-HV8701B-RAN	RHR SUCTION MOV HV8701B FAILS (RANDOM)	0.0078
61	1-RHR-MOV-RP-HV8702A-RAN	RHR SUCTION MOV HV8702A FAILS (RANDOM)	0.0078
62	1-RHR-MOV-RP-HV8702B-RAN	RHR SUCTION MOV HV8702B FAILS (RANDOM)	0.0078

Table B.2: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Early Fatality Risk (0–1.8 Miles)

	Basic Event	Description	Composite FV
63	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0075
64	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0071
65	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0064
66	1-ACP-BAC-MA-BB16____	480V SWITCHGEAR 1BB16 IN MAINTENANCE	0.0063
67	1-IE-SGTR	SGTR	0.0062
68	1-IE-OTRANS	OTHER TRANSIENT	0.0059
69	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0057
70	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0055

Table B.3: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Early Fatalities (0–50 Miles)

	Basic Event	Description	Composite FV
1	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.6030
2	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.5635
3	1-IE-ISL-RHR-CLI-A	RHR COLD LEG INJECTION TRAIN A ISOLATION	0.1113
4	1-IE-ISL-RHR-CLI-B	RHR COLD LEG INJECTION TRAIN B ISOLATION	0.1113
5	1-IE-RHR-MOV-RP-HV8701B	RHR SUCTION MOV HV8701B (ISLOCA INITIATOR)	0.1037
6	1-IE-RHR-MOV-RP-HV8702B	RHR SUCTION MOV HV8702B (ISLOCA INITIATOR)	0.1037
7	1-RHR-MOV-RP-HV8701A-CON	RHR SUCTION MOV HV8701A FAILS (CONDITIONAL)	0.0959
8	1-RHR-MOV-RP-HV8702A-CON	RHR SUCTION MOV HV8702A FAILS (CONDITIONAL)	0.0959
9	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0958
10	1-IE-RHR-MOV-CO-HV8701A	RHR SUCTION MOV HV8701A TRANSFERS OPEN (ISLOCA INITIATOR)	0.0950
11	1-IE-RHR-MOV-CO-HV8701B	RHR SUCTION MOV HV8701B TRANSFERS OPEN (ISLOCA INITIATOR)	0.0950
12	1-IE-RHR-MOV-CO-HV8702A	RHR SUCTION MOV HV8702A TRANSFERS OPEN (ISLOCA INITIATOR)	0.0950
13	1-IE-RHR-MOV-CO-HV8702B	RHR SUCTION MOV HV8702B TRANSFERS OPEN (ISLOCA INITIATOR)	0.0950
14	1-RHR-MOV-CO-HV8701A_	RHR SUCTION MOV HV8701A TRANSFERS OPEN	0.0950
15	1-RHR-MOV-CO-HV8701B_	RHR SUCTION MOV HV8701A TRANSFERS OPEN	0.0950
16	1-RHR-MOV-CO-HV8702A_	RHR SUCTION MOV HV8702A TRANSFERS OPEN	0.0950
17	1-RHR-MOV-CO-HV8702B_	RHR SUCTION MOV HV8702B TRANSFERS OPEN	0.0950
18	1-RHR-MOV-OO-HV8809A-HDP	LP CL INJ MOV HV8809A FAILS TO CLOSE WITH HIGH DIFFERENTIAL PRESSURE	0.0855
19	1-RHR-MOV-OO-HV8809B-HDP	LP CL INJ MOV HV8809B FAILS TO CLOSE WITH HIGH DIFFERENTIAL PRESSUIRE	0.0855

Table B.3: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Early Fatalities (0–50 Miles)

	Basic Event	Description	Composite FV
20	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0644
21	1-IE-ISL-RCP-S1LO	RCP STAGE 1 SEAL ISOLATION	0.0634
22	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.0595
23	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.0593
24	1-IE-HPI-CKV-RP-083_____	ECCS CL1 INJ CV083 Rupture (ISLOCA INI>)	0.0556
25	1-IE-HPI-CKV-RP-084_____	ECCS CL 2 INJ CV 084 Rupture (ISLOCA INI)	0.0556
26	1-IE-HPI-CKV-RP-085_____	ECCS CL 3 INJ CV 085 Rupture (ISLOCA INI)	0.0556
27	1-IE-HPI-CKV-RP-086_____	ECCS CL4 INJ CV 086 Rupture (ISLOCA INI)	0.0556
28	1-RHR-CKV-RP-147__CON	RHR CL 1 INJ CV 147 Fails (Conditional)	0.0556
29	1-RHR-CKV-RP-148__CON	RHR CL 2 INJ CV 148 fails (Conditional)	0.0556
30	1-RHR-CKV-RP-149__CON	RHR CL 3 INJ CV 149 fails (Conditional)	0.0556
31	1-RHR-CKV-RP-150__CON	RHR CL 4 INJ CV 150 fails (Conditional)	0.0556
32	1-L2-BE-ISLOCASUBM-SM	ISLOCA Break Not Submerged or Significantly Scrubbed for Small ISLOCAs	0.0533
33	1-OA-IS-ISLRHR-H	OPERATOR FAILS TO ISOLATE ISLOCA THROUGH RHR COLD LEG INJECTION LINES	0.0482
34	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.0468
35	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.0391
36	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.0386
37	1-L2-BE-ABFH2-FANS	Aux Bldg Failure due to Combustion (Ventilation)	0.0365
38	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.0291
39	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.0273
40	1-L2-BE-ABFANS-IND-FAIL	Independent or Induced Failure of Aux Bldg Ventilation	0.0269

Table B.3: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Early Fatalities (0–50 Miles)

	Basic Event	Description	Composite FV
41	1-L2-BE-ABFH2-NOFANS	Aux Bldg Failure due to Combustion (No Ventilation)	0.0256
42	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.0247
43	1-OA-IS-ISLSEALSBO	OPERATOR FAILS TO ISOLATE RCP SEAL LINES at LOCAL -ISLOCA w SBO	0.0245
44	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.0225
45	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0154
46	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0133
47	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0124
48	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0118
49	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0112
50	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0105
51	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0098
52	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0096
53	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0089
54	1-ACP-BAC-MA-MCCBBB__	480V MCC 1BBB IN MAINTENANCE	0.0080
55	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0079
56	1-IE-RHR-MOV-RP-HV8701A	RHR SUCTION MOV HV8701A (ISLOCA INITIATOR)	0.0078
57	1-IE-RHR-MOV-RP-HV8702A	RHR SUCTION MOV HV8702A (ISLOCA INITIATOR)	0.0078
58	1-RHR-MOV-RP-HV8701A-RAN	RHR SUCTION MOV HV8701A FAILS (RANDOM)	0.0078
59	1-RHR-MOV-RP-HV8701B-RAN	RHR SUCTION MOV HV8701B FAILS (RANDOM)	0.0078
60	1-RHR-MOV-RP-HV8702A-RAN	RHR SUCTION MOV HV8702A FAILS (RANDOM)	0.0078
61	1-RHR-MOV-RP-HV8702B-RAN	RHR SUCTION MOV HV8702B FAILS (RANDOM)	0.0078

Table B.3: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Early Fatalities (0–50 Miles)			
	Basic Event	Description	**Composite FV**
62	1-L2-OP-SCG1-3	Operator Fails to Carry Out SCG-1 (F&B SGs - Late)	0.0077
63	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0074
64	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0071
65	1-ACP-BAC-MA-BB16____	480V SWITCHGEAR 1BB16 IN MAINTENANCE	0.0063
66	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0063
67	1-IE-SGTR	SGTR	0.0061
68	1-IE-OTRANS	OTHER TRANSIENT	0.0057
69	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0056
70	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0054

Table B.4: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Latent Cancer Fatality Risk (0–10 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4646
2	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3714
3	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3185
4	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2478
5	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.2303
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2172
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2121
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2119
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1752
10	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1656
11	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1642
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1590
13	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1515
14	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1434
15	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1396
16	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1325
17	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1267
18	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1164
19	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1119
20	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1103
21	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.1038
22	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.1029

Table B.4: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Latent Cancer Fatality Risk (0–10 Miles)

	Basic Event	Description	Composite FV
23	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0882
24	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.0818
25	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0814
26	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.0754
27	1-IE-LONSCW	LOSS OF NSCW	0.0738
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0737
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0728
30	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0714
31	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0570
32	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0541
33	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0534
34	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0507
35	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0488
36	1-IE-OTRANS	OTHER TRANSIENT	0.0483
37	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0476
38	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0456
39	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0400
40	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0337
41	1-IE-MLOCA	MEDIUM LOCA	0.0321
42	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0319
43	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0313
44	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0275
45	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0268
46	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0264
47	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0262

Table B.4: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Latent Cancer Fatality Risk (0–10 Miles)			
	Basic Event	**Description**	**Composite FV**
48	1-EPS-DGN-FS-G4002____	DG1B FAILS TO START BY RANDOM CAUSE	0.0227
49	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0225
50	1-EPS-DGN-FS-G4001____	DG1A FAILS TO START BY RANDOM CAUSE	0.0223
51	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0214
52	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0214
53	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0202
54	1-IE-TTRIP	TURBINE TRIP	0.0201
55	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0193
56	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0191
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0184
58	1-DCP-BDC-FC-BD1&_____	125V BUS 1BD1 FAILS (1YR)	0.0184
59	1-IE-RTRIP	REACTOR TRIP	0.0183
60	1-ACP-BAC-MA-AA02_____	BUS 1AA02 IN MAINTENANCE	0.0177
61	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0166
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0160
63	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0152
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0147
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0134
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0132
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0127
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0122
69	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0103
70	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0096
71	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP	0.0089

Table B.4: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Population-Weighted Individual Latent Cancer Fatality Risk (0–10 Miles)

	Basic Event	Description	Composite FV
		OPERATION (COMPLETE DEPENDENCE)	
72	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0083
73	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0081
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0080
75	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0076
76	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0072
77	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0065
78	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0063
79	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0060
80	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0058
81	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0058
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0058
83	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0058
84	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0058
85	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0058
86	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0054

Table B.5a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4577
2	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3564
3	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3124
4	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3026
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2435
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2257
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2227
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2221
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1721
10	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1680
11	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1612
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1557
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1495
14	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1463
15	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1451
16	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1301
17	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1266
18	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1246
19	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1166
20	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1127
21	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1098
22	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1089

Table B.5a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.1007
24	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0863
25	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0818
26	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0799
27	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0723
28	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0714
29	1-IE-LONSCW	LOSS OF NSCW	0.0714
30	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0702
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0688
32	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0552
33	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0532
34	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0523
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0513
36	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0479
37	1-IE-OTRANS	OTHER TRANSIENT	0.0476
38	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0467
39	1-IE-MLOCA	MEDIUM LOCA	0.0451
40	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0402
41	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0391
42	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0346
43	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0330
44	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0313
45	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0309
46	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0302

Table B.5a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
47	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0264
48	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0264
49	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0259
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0222
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0218
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0210
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0209
54	1-IE-TTRIP	TURBINE TRIP	0.0197
55	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0196
56	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0190
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0182
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0182
59	1-IE-RTRIP	REACTOR TRIP	0.0180
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0175
61	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0159
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0157
63	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0155
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0145
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0133
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0130
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0122
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0118
69	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0099
70	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0094
71	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0088

Table B.5a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
72	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0086
73	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0081
74	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0079
75	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0073
76	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0073
77	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0070
78	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0063
79	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0062
80	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0061
81	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0059
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0057
83	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0057
84	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0057
85	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0056
86	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0056
87	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0052

Table B.5b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4561
2	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3514
3	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3159
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3104
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2421
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2261
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2240
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2233
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1710
10	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1676
11	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1603
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1546
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1501
14	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1454
15	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1442
16	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1351
17	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1296
18	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1245
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1237
20	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1114
21	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1092
22	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1084

Table B.5b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0999
24	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0857
25	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0794
26	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0771
27	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0748
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0718
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0710
30	1-IE-LONSCW	LOSS OF NSCW	0.0704
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0679
32	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0545
33	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0529
34	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0520
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0516
36	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0476
37	1-IE-MLOCA	MEDIUM LOCA	0.0475
38	1-IE-OTRANS	OTHER TRANSIENT	0.0473
39	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0464
40	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0429
41	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0389
42	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0369
43	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0359
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0327
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0311
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0307

Table B.5b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0262
48	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0260
49	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0258
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0221
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0217
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0209
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0208
54	1-IE-TTRIP	TURBINE TRIP	0.0196
55	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0194
56	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0189
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0182
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0182
59	1-IE-RTRIP	REACTOR TRIP	0.0179
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0175
61	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0156
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0155
63	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0155
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0144
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0133
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0129
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0120
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0117
69	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0098
70	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0094
71	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0090

Table B.5b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Latent Cancer Fatalities (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
72	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0085
73	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0083
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0082
75	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0079
76	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0074
77	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0073
78	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0072
79	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0062
80	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0062
81	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0058
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0057
83	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0057
84	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0056
85	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0056
86	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0056
87	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0052
88	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0051

Table B.6a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km² Cs-137 (0–50 Miles)

	Basic Event	Description	Composite FV
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4522
2	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3248
3	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3115
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3038
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2383
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2110
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2102
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2094
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1676
10	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1570
11	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1535
12	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1510
13	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1461
14	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1404
15	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1357
16	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1346
17	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1290
18	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1279
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1124
20	1-EPS-DGN-FR-G4001____	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1073
21	1-EPS-DGN-FR-G4002____	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1070
22	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.1048

Table B.6a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.0994
24	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0974
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0835
26	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0808
27	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0775
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0704
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0697
30	1-IE-LONSCW	LOSS OF NSCW	0.0634
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0603
32	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0596
33	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0544
34	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0520
35	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0508
36	1-IE-MLOCA	MEDIUM LOCA	0.0500
37	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0491
38	1-IE-OTRANS	OTHER TRANSIENT	0.0466
39	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0464
40	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0463
41	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0454
42	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0399
43	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0379
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0319
45	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0305

Table B.6a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
46	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0304
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0256
48	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0252
49	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0231
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0215
51	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0214
52	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0212
53	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0207
54	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0204
55	1-IE-TTRIP	TURBINE TRIP	0.0192
56	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0185
57	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0185
58	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0182
59	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0182
60	1-IE-RTRIP	REACTOR TRIP	0.0175
61	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0174
62	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0156
63	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0152
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0141
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0138
66	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0138
67	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0126
68	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0108
69	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.0108
70	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0106

Table B.6a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
71	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0106
72	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0092
73	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0088
74	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0087
75	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0085
76	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0080
77	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0078
78	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0076
79	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0065
80	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0060
81	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0060
82	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0058
83	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0058
84	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0057
85	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0055
86	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0055
87	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0055
88	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0055
89	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0055
90	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0051

Table B.6b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4496
2	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.3089
3	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.3005
4	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.2957
5	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2366
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2007
7	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.1997
8	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.1990
9	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1658
10	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1556
11	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1493
12	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1458
13	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.1390
14	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1335
15	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.1316
16	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1290
17	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1281
18	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1270
19	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1226
20	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1069
21	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1069
22	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1058

Table B.6b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km² Cs-137 (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0963
24	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.0945
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0826
26	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.0769
27	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0763
28	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0696
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0690
30	1-IE-LONSCW	LOSS OF NSCW	0.0603
31	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0572
32	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0564
33	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0550
34	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0516
35	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0502
36	1-IE-MLOCA	MEDIUM LOCA	0.0477
37	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0468
38	1-IE-OTRANS	OTHER TRANSIENT	0.0462
39	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0459
40	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0449
41	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0440
42	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0380
43	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0375
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0316
45	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0302

Table B.6b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
46	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0300
47	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0281
48	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0253
49	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0250
50	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0219
51	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0212
52	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0210
53	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0205
54	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0202
55	1-IE-TTRIP	TURBINE TRIP	0.0190
56	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0183
57	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0183
58	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0183
59	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0182
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0174
61	1-IE-RTRIP	REACTOR TRIP	0.0174
62	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0155
63	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0150
64	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.0147
65	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0145
66	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0141
67	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0131
68	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0125
69	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0123
70	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0120

Table B.6b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km^2 Cs-137 (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
71	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0103
72	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0101
73	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0096
74	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0091
75	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0087
76	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0087
77	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0083
78	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0078
79	1-L2-OP-SCG1-3	Operator Fails to Carry Out SCG-1 (F&B SGs - Late)	0.0075
80	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0072
81	1-IE-SGTR	SGTR	0.0065
82	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0062
83	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0060
84	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0060
85	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0060
86	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0056
87	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0055
88	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0054
89	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0054
90	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0052
91	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0052

Table B.6b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Land Area Exceeding 15 Ci/km² Cs-137 (0–100 Miles)

	Basic Event	Description	Composite FV
92	1-IE-ISL-RHR-CLI-A	RHR COLD LEG INJECTION TRAIN A ISOLATION	0.0052
93	1-IE-ISL-RHR-CLI-B	RHR COLD LEG INJECTION TRAIN B ISOLATION	0.0052
94	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0050

Table B.7a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.4971
2	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4382
3	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3233
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.2975
5	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2611
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2598
7	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2594
8	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.2457
9	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2312
10	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.2264
11	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1772
12	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1725
13	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1671
14	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1647
15	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1534
16	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1475
17	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1378
18	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.1358
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1257
20	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1235
21	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1061
22	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1059

Table B.7a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1055
24	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0948
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0813
26	1-IE-MLOCA	MEDIUM LOCA	0.0802
27	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0790
28	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0776
29	1-IE-LONSCW	LOSS OF NSCW	0.0692
30	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0686
31	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0679
32	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0669
33	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0632
34	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0539
35	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0536
36	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0511
37	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0499
38	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0456
39	1-IE-OTRANS	OTHER TRANSIENT	0.0454
40	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0446
41	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0445
42	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0369
43	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0311
44	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0307
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0298

Table B.7a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0295
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0252
48	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0248
49	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0240
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0211
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0207
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0199
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0198
54	1-IE-TTRIP	TURBINE TRIP	0.0187
55	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0183
56	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0180
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0175
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0175
59	1-IE-RTRIP	REACTOR TRIP	0.0171
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0168
61	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0162
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0148
63	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0141
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0140
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0129
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0125
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0117
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0116
69	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0101
70	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0096

Table B.7a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
71	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0095
72	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0092
73	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0088
74	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0087
75	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0082
76	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0080
77	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0076
78	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0073
79	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0071
80	1-L2-BE-H2CF-L-CHRPB	Late CF from Burn (with CHR, with prior burn)	0.0065
81	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0059
82	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0059
83	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0056
84	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0056
85	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0055
86	1-AFW-MDP-MA-P4002___	MDAFWP B (P4-002) UNAVAILABLE DUE TO T&M	0.0055
87	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0054
88	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0053
89	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0053

Table B.7b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.4990
2	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4357
3	1-L2-BE-H2IGNSRC-E-NAC	No Ignition Source in Containment at VB, without AC Power	0.3207
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.2959
5	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2609
6	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2596
7	1-L2-BE-H2IGNSRC-E-AC	No Ignition Source in Containment at VB, with Power	0.2591
8	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.2472
9	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2301
10	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.2278
11	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1765
12	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1723
13	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1669
14	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1639
15	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1527
16	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER- RELA TED)	0.1467
17	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1370
18	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.1366
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1252
20	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1228
21	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1059
22	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1054

Table B.7b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–100 Miles)			
	Basic Event	Description	Composite FV
23	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermeidate pressure)	0.1048
24	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0942
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0808
26	1-IE-MLOCA	MEDIUM LOCA	0.0806
27	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0787
28	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0780
29	1-IE-LONSCW	LOSS OF NSCW	0.0689
30	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0682
31	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0675
32	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0673
33	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0627
34	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0538
35	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0534
36	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0509
37	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0496
38	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0454
39	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0453
40	1-IE-OTRANS	OTHER TRANSIENT	0.0452
41	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0443
42	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0367
43	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0309
44	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0297

Table B.7b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
45	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0295
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0293
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0250
48	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0247
49	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0239
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0210
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0206
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0198
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0197
54	1-IE-TTRIP	TURBINE TRIP	0.0186
55	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0182
56	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0179
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0175
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0175
59	1-IE-RTRIP	REACTOR TRIP	0.0170
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0167
61	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0162
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0147
63	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0142
64	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0140
65	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0129
66	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0124
67	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0117
68	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0116

Table B.7b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
69	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0114
70	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0101
71	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0095
72	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0092
73	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0091
74	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0088
75	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0083
76	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0082
77	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0075
78	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0075
79	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0071
80	1-L2-BE-H2CF-L-CHRPB	Late CF from Burn (with CHR, with prior burn)	0.0066
81	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.0059
82	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0059
83	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0059
84	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0056
85	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0056
86	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0056
87	1-AFW-MDP-MA-P4002___	MDAFWP B (P4-002) UNAVAILABLE DUE TO T&M	0.0055

Table B.7b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Population Affected by Intermediate-Phase Relocation (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
88	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0053
89	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0053
90	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0053
91	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0050

Table B.8a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4387
2	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.4276
3	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3171
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.2999
5	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2445
6	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2414
7	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2400
8	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2332
9	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.2058
10	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1896
11	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1672
12	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1659
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1600
14	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1572
15	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1545
16	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1488
17	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1368
18	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1238
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1206
20	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.1138
21	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1068
22	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1064

Table B.8a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
23	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1027
24	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0958
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0821
26	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0789
27	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0691
28	1-IE-LONSCW	LOSS OF NSCW	0.0686
29	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0684
30	1-IE-MLOCA	MEDIUM LOCA	0.0683
31	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0651
32	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0629
33	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0619
34	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0562
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0538
36	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0531
37	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0515
38	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0502
39	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0459
40	1-IE-OTRANS	OTHER TRANSIENT	0.0455
41	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0448
42	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0423
43	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0373
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0314
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0300
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0296

Table B.8a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0253
48	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0249
49	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0240
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0212
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0209
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0200
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0198
54	1-IE-TTRIP	TURBINE TRIP	0.0187
55	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0184
56	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0182
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0176
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0176
59	1-IE-RTRIP	REACTOR TRIP	0.0171
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0169
61	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0160
62	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0150
63	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0142
64	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0140
65	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0138
66	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0132
67	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0125
68	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0117
69	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0115
70	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0096
71	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0095
72	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0093

Table B.8a: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–50 Miles)			
	Basic Event	**Description**	**Composite FV**
73	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0089
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0083
75	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0082
76	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0077
77	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0076
78	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0075
79	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0070
80	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.0069
81	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0059
82	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0059
83	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0056
84	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0056
85	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0056
86	1-L2-BE-H2CF-L-CHRPB	Late CF from Burn (with CHR, with prior burn)	0.0055
87	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0054
88	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0054
89	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0053
90	1-AFW-MDP-MA-P4002___	MDAFWP B (P4-002) UNAVAILABLE DUE TO T&M	0.0053
91	1-OEP-XHE-XX-NR02HGR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-GR Avail)	0.0050

Table B.8b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
1	1-L2-BE-MANUALTDAFW-GEN	Failure of Manual Extension of TD-AFW in SBO	0.4387
2	1-L2-BE-H2IGNSRC-L-NAC	Ignition Source in Containment Late, without AC Power	0.4195
3	1-L2-BE-H2IGNSRC-E-NAC	Ignition Source in Containment at VB, without AC Power	0.3161
4	1-IE-LOOPGR	LOSS OF OFFSITE POWER (GRID-RELATED)	0.2990
5	1-L2-BE-H2IGNSRC-VE-AC	Ignition Source in Containment before VB, with AC Power	0.2404
6	1-L2-BE-H2IGNSRC-L-AC	Ignition Source in Containment Late, with Power	0.2379
7	1-L2-BE-H2IGNSRC-E-AC	Ignition Source in Containment at VB, with Power	0.2366
8	1-ACP-CRB-CF-A205301	CCF OF SWITCHYARD AC BREAKERS AA205 & BA301 TO OPEN	0.2330
9	1-L2-BE-H2CF-L-NACNPB	Late CF from Burn (without AC, without prior burn)	0.2011
10	1-L2-BE-H2CF-L-NACPB	Late CF from Burn (without AC, with prior burn)	0.1853
11	1-L2-OP-SCG1-1	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Firewater)	0.1659
12	1-IE-LOOPSC	LOSS OF OFFSITE POWER (SWITCHYARD- CENTERED)	0.1654
13	1-L2-BE-H2IGN-E-PB	Combustion in Containment at VB given Prior Burn	0.1578
14	1-L2-BE-H2IGN-VE-GEN	Combustion in Containment before VB (General)	0.1546
15	1-EPS-SEQ-CF-FOAB	SEQUENCERS FAIL FROM COMMON CAUSE TO OPERATE	0.1543
16	1-IE-LOOPWR	LOSS OF OFFSITE POWER (WEATHER-RELATED)	0.1484
17	1-RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.1354
18	1-OEP-VCF-LP-CLOPT	CONSEQUENTIAL LOSS OF OFFSITE POWER - TRANSIENT	0.1239
19	1-L2-BE-IVREC	No IVR, Vessel Breach Occurs	0.1192
20	1-L2-BE-H2CF-L-NCHRPB	Late CF from Burn (without CHR, with prior burn)	0.1112
21	1-EPS-DGN-FR-G4001___	DG1A FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1065
22	1-EPS-DGN-FR-G4002___	DG1B FAILS TO RUN BY RANDOM CAUSE (24 HR MISSION TIME)	0.1059

Table B.8b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–100 Miles)

	Basic Event	Description	Composite FV
23	1-L2-BE-INDHLF-MP	Induced Hot Leg Failure (Intermediate pressure)	0.1022
24	1-OEP-XHE-XL-NR02HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (GRID-RELATED)	0.0956
25	1-OEP-XHE-XL-NR02HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS (WEATHER-RELATED)	0.0820
26	1-OA-ORS-------H	OPERATOR FAILS TO RESTORE SYSTEMS AFTER AC RECOVERED IN SBO	0.0782
27	1-ACP-CRB-CC-BA0301__	RAT B SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0690
28	1-ACP-CRB-CC-AA0205__	RAT A SUPPLY CRB RANDOMLY FAILS TO OPEN	0.0683
29	1-IE-LONSCW	LOSS OF NSCW	0.0676
30	1-IE-MLOCA	MEDIUM LOCA	0.0668
31	1-L2-BE-INDSGTR-HDL	Induced SGTR given High/Dry/Low	0.0654
32	1-L2-BE-H2DET-L-CHR	Late Detonation with CHR	0.0636
33	1-L2-BE-H2IGNSRC-VE-NAC	Ignition Source in Containment before VB, without AC Power	0.0616
34	1-OAR_HPML-----H	OPERATOR FAILS TO ESTABLISH HIGH PRESSURE RECIRCULATION - MLOCA	0.0549
35	1-L2-OP-SAG1	Operator Fails to Carry Out SAG-1 (Open 2 ARVs and Feed SGs)	0.0535
36	1-IE-SWS-MDP-CR-123456	System Generated Event based upon Rasp CCF event : 1-IE-SWS-MDP-CF-	0.0524
37	1-EPS-DGN-MA-G4001___	DG1A IN MAINTENANCE	0.0514
38	1-EPS-DGN-MA-G4002___	DG1B IN MAINTENANCE	0.0501
39	1-EPS-SEQ-FO-1821U302	SEQUENCER B FAILS TO OPERATE	0.0457
40	1-IE-OTRANS	OTHER TRANSIENT	0.0455
41	1-EPS-SEQ-FO-1821U301	SEQUENCER A FAILS TO OPERATE	0.0447
42	1-L2-BE-CONTOP-NCHR	Containment Overpressure Failure Late (No CHR)	0.0430
43	1-OEP-XHE-XX-NR02HWR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-WR AVAIL)	0.0372
44	1-OEP-XHE-XX-NR02HGR1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR-GR AVAIL)	0.0313
45	1-IE-LOOPPC	LOSS OF OFFSITE POWER (PLANT-CENTERED)	0.0299

Table B.8b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
46	1-AFW-TDP-FR-P4001___	TDAFWP (P4-001) FAILS TO RUN	0.0296
47	1-DCP-BAT-MA-BD1B____	BATTERY 1BD1B IN MAINTENANCE	0.0252
48	1-DCP-BAT-MA-AD1B____	BATTERY 1AD1B IN MAINTENANCE	0.0249
49	1-L2-BE-PZRVSTUCK-SRV	Pressurizer SRVs Do Not Fail Open During CD	0.0238
50	1-EPS-DGN-FS-G4002___	DG1B FAILS TO START BY RANDOM CAUSE	0.0212
51	1-EPS-DGN-FS-G4001___	DG1A FAILS TO START BY RANDOM CAUSE	0.0208
52	1-CVC-MDP-FR-NCP4001&	NORMAL CHARGING PUMP 1208P4001 FAILS TO RUN (1 YEAR)	0.0200
53	1-IE-LOSINJ	LOSS OF SEAL INECTION	0.0198
54	1-IE-TTRIP	TURBINE TRIP	0.0187
55	1-EPS-DGN-CF-FRUN1	CCF OF UNIT 1 DGNS G4001/G4002 TO RUN	0.0183
56	1-NSCWCT-SPRAY	NSCW CTS IN SPRAY MODE (fraction of time)	0.0182
57	1-IE-LO125BD1	LOSS OF DC BUS 1BD1 SPECIAL INITIATOR IDENTIFIER	0.0177
58	1-DCP-BDC-FC-BD1&____	125V BUS 1BD1 FAILS (1YR)	0.0177
59	1-IE-RTRIP	REACTOR TRIP	0.0171
60	1-ACP-BAC-MA-AA02____	BUS 1AA02 IN MAINTENANCE	0.0169
61	1-IE-LO4160VA	LOSS OF 4.16KV BUS A	0.0160
62	1-IE-ISL-RHR-HLS	RHR HOT LEG SUCTION ISOLATION	0.0157
63	1-OEP-XHE-XX-NR02HWR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-WR AVAIL)	0.0149
64	1-IE-SSBO	SECONDARY SIDE BREAK OUTSIDE OF MSIVs	0.0144
65	1-L2-BE-H2IGN-VE-SBO	Combustion in Containment before VB (SBO)	0.0139
66	1-RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	0.0133
67	1-IE-LO4160VB	LOSS OF 4.16KV BUS B	0.0125
68	1-RCS-XHE-XM-TRIP	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS	0.0115
69	1-OA-NSCWFAN---H	OPERATOR FAILS TO START NSCW FAN MANUALLY (PLACE HOLDER)	0.0113
70	1-OEP-VCF-LP-CLOPL	CONSEQUENTIAL LOSS OF OFFSITE POWER - LOCA	0.0100

Table B.8b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–100 Miles)			
	Basic Event	**Description**	**Composite FV**
71	1-OAB_TR-------H	OPERATOR FAILS TO FEED AND BLEED - TRANSIENT	0.0095
72	1-RCS-XHE-XM-TRIP-LONSCW	OPERATOR FAILS TO TRIP REACTOR COOLANT PUMPS (LONSCW)	0.0093
73	1-OEP-XHE-XL-NR01HGR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (GRID-RELATED)	0.0089
74	1-IE-LOMFW	LOSS OF MAIN FEED WATER	0.0086
75	1-OA-OSW-------H-CD	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION (COMPLETE DEPENDENCE)	0.0081
76	1-L2-BE-ISLOCASUBM-LRG	ISLOCA Break Not Submerged or Significantly Scrubbed for Large ISLOCAs	0.0079
77	1-IE-LOCHS	LOSS OF CONDENSER HEAT SINK	0.0078
78	1-ACP-BAC-MA-BA03____	4.16KV BUS 1BA03 IN MAINTENANCE	0.0076
79	1-L2-OP-SCG1-4	Operator Fails to Carry Out SCG-1 (Spray Containment w/ Cont. Spray System)	0.0075
80	1-OA-OSW-------H	OPERATOR FAILS TO ESTABLISH SINGLE PUMP NSCW PUMP OPERATION	0.0069
81	1-L2-OP-SCG1-2	Operator Fails to Carry Out SCG-1 (F&B SGs)	0.0064
82	1-OEP-XHE-XX-NR02HWR0	CONVOLUTION FACTOR FOR CCF-OPR (2HR-WR Avail)	0.0059
83	1-L2-OP-SAG2-1	Operator Fails to Carry Out SAG-2 (Open all ARVs - Not Depress)	0.0058
84	1-IE-LO125AD1	LOSS OF DC BUS 1AD1 SPECIAL INITIATOR IDENTIFIER	0.0057
85	1-DCP-BDC-FC-AD1&____	125V BUS 1AD1 FAILS (1YR)	0.0057
86	1-EPS-DGN-CF-FSUN1	CCF OF UNIT 1 DGNs G4001/G4002 TO START	0.0056
87	1-EPS-MDP-FS-XFERPPS_-CC	CCF OF DG FUEL TRANSFER PUMPS TO START	0.0054
88	1-OEP-XHE-XX-NR02HGR2	CONVOLUTION FACTOR FOR 2FTR-OPR (2HR-GR AVAIL)	0.0054
89	1-L2-BE-H2CF-L-CHRPB	Late CF from Burn (with CHR, with prior burn)	0.0053

Table B.8b: Composite FV Importance Measure Results for Basic Events Identified as Significant Contributors to Mean Annual Risk of Total Economic Costs (0–100 Miles)

	Basic Event	Description	Composite FV
90	1-OEP-XHE-XL-NR01HWR	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR (WEATHER-RELATED)	0.0053
91	1-AFW-MDP-MA-P4002___	MDAFWP B (P4-002) UNAVAILABLE DUE TO T&M	0.0052