Standard for Radiological Accident Offsite Consequence Analysis (Level 3 PRA) to Support Nuclear Installation Applications

TRIAL USE AND PILOT APPLICATION

Publication of this Standard for trial use has been approved by The American Society of Mechanical Engineers and the American Nuclear Society. Distribution of this Standard for trial use and comment shall not continue beyond 24 months from the date of publication, unless this period is extended by action of the Joint Committee on Nuclear Risk Management. It is expected that following this 24-month period, this draft Standard, revised as necessary, will be submitted to the American National Standards Institute (ANSI) for approval as an American National Standard. A public review in accordance with established ANSI procedures is required at the end of the trial-use period and before a Standard for trial use may be submitted to ANSI for approval as an American National Standard. This trial-use Standard is not an American National Standard.

Comments and suggestions for revision should be submitted to:

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FOREWORD

The American Nuclear Society (ANS) Standards Board and the American Society of Mechanical Engineers (ASME) Board on Nuclear Codes and Standards (BNCS) mutually agreed in 2004 to form a Nuclear Risk Management Coordinating Committee (NRMCC). This committee was chartered to coordinate and harmonize standards activities related to probabilistic risk assessment (PRA) between the two standards developing organizations (SDOs). A key activity resulting from the NRMCC was direction to the ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM) to develop PRA standards structured around the three Levels of PRA (i.e., Level 1, Level 2, Level 3) to be jointly issued by the two societies.

This Standard sets forth requirements for determining consequences (i.e., Level 3, also referred to as L3 in this Standard) as part of PRAs and related analysis methodologies that can be used to support risk-informed decisions for commercial nuclear power plants. This Standard also prescribes a process for applying these requirements for certain other applications involving release of radioactive materials into the atmosphere (e.g., non-light water reactor (LWR) nuclear power plants, research reactors, fuel cycle facilities, and non-reactor nuclear Department of Energy (DOE) facilities). In these cases, supplemental requirements may be needed to ensure technical adequacy.

This Standard was developed based on the body of knowledge and experience accumulated through the development and application of the ASME/ANS RA-Sb-2013, "Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," and Level 2 PRA Standard ASME/ANS RA-S-1.2-2014, "Severe Accident Progression and Radiological Release (Level 2) PRA Standard for Nuclear Power Plant Applications for Light Water Reactors (LWRs)," which has been approved for trial use and pilot application. This Standard, however, is not dependent upon these other PRA standards, although it is noted that the development of the final risk estimation for reactors will be based on combining the results of the Level 1 and Level 2 (Level 1/2) PRA portions (e.g., release frequencies, release characterizations) and the results of the consequence analysis.

Consequences covered within the scope of this Standard include radiation dose and induced health effects, and economic impacts, taking into account atmospheric dispersion, demography, dosimetry, pathways to man, and plant/site characteristics. The radioactive source terms and their frequencies often are passed on from Level 1/2 analyses.

The scope of a PRA covered by this Standard is primarily targeted for use to determine the impact of an accident at a nuclear power plant. However, the technology discussed here can be used to determine the impact of a release of radioactive material from any facility. A Level 3 analysis can use the results of a Level 1 analysis followed by a Level 2 analysis or the results of a combined Level 1/2 analysis (e.g., gas-cooled or other advanced reactors).

This Standard describes requirements for calculating the consequences of radionuclide releases into the environment and how to present the results of such calculations. It is assumed that a computerized consequence model will be used. Therefore, emphasis has been placed on the information that is typically required as input and available output. As with any computer code, there are pitfalls associated with its use, and there are uncertainties inherent in the quality and representativeness of the input data and the fidelity of the modeling. This Standard attempts to caution against improper use of consequence analysis tools.

This Standard contains a brief description of each major requirement to perform a consequence analysis, and explains why it is necessary, what information results, and how it is to be used. The technical requirements for the various technical elements of a consequence analysis include (1) transport and dispersion in the atmosphere; (2) deposition processes; (3) processes that lead to the accumulation of radiation doses; (4) protective measures, such as evacuation, that can reduce radiation doses; (5) the effects of radiation doses on the human body; and (6) economic impacts. A section is also included describing how the combined risk results of a Level 1, 2, and 3 PRA can be presented. This process is referred to as “risk estimation.”

It is acknowledged that some topics are subject to argument and continuing development, since consequence modeling is not a precise science and contains significant inherent uncertainties. Where an understanding of the current state-of-the-art is deemed necessary for a sensible interpretation of the results, a discussion of this topic is included. Other areas that are described in some depth are those in which the user's choice of input data can significantly affect the output. Examples include evacuation and sheltering, and dry deposition velocity.

Appendix A, Computer Codes, has been included in this Standard to provide some history and to illustrate typical input parameters and output reports of the calculation results from an acceptable computer code.

This Standard might reference documents and other standards that will have been superseded or withdrawn at the time the Standard is applied. A statement has been included in the reference section that provides guidance on the use of references.

The format for this Standard was developed in 2005 when no “standard” format was available. Therefore, it is not consistent with some other published PRA standards regarding chapter numbers. Following trial use, the format of the section numbering will be re-evaluated.

This Standard is issued for trial use and pilot application. Feedback is requested regarding the Standard in all areas including the following:

- Were the format changes that vary slightly from other contemporary PRA standards helpful? This includes descriptors added for each supporting requirement (SR).
- Were the technical SRs and action verbs clear?
- Notes have been included for a number of SRs. Do these notes result in lack of clarity regarding what is required and what is provided as added information? Are these notes helpful?
- Is the information provided in Appendix A useful?
- The bases for Capability Categories (i.e., Table 1-1) in this Standard differ from the other PRA standards in that two attributes are used (i.e., site specificity and model realism) rather than three attributes (i.e., scope and level of detail, plant specificity, and realism). It is thought that the scope and level of detail attribute is adequately addressed by the model realism attribute for Level 3 analyses, and that site specificity is more appropriate than plant specificity. Comments on this change are of interest.
- Capability Category III is expected to be deleted from this Standard (consistent with planned changes to the Level 1 and Level 2 PRA standards) following the trial use and pilot application period. Are there requirements in Capability Category III that should be considered for incorporation into Capability Category II rather than deletion?
- Some SRs contain multiple actions verbs (e.g., PA-B1, ME-A3). Did the inclusion of multiple action verbs in a single SR result in complications in meeting the requirements or assessing their completion as part of a Peer Review?
- Were uncertainty requirements easily understood and implemented?

- Were the minimum requirements for peer review teams reasonable (number of members, composition)?
- Was Section 5 on risk estimation used in your application, and if so were the requirements clear?
- The application process in Section 3 differs slightly from that of other PRA standards. Was the application process (e.g., flowchart in Figure 3-1) applicable (including references to Level 1 and Level 2 PRA scope)? If so did you have trouble applying the process?
- The ASME/ANS PRA standards have been developed in view of assessing the capability of a “base” PRA. It is recognized that nuclear facilities in the past have typically only developed Level 3 PRAs for specific applications, which may vary considerably, and were not maintained. Based on this historical usage of Level 3 PRA for specific applications, which may vary, this Standard has included some flexibility in the supporting requirements (e.g., no requirement for economic cost modeling or protective-action modeling for Capability Category I.) Are there areas where more or less specificity would be helpful in the supporting requirements in view of maintaining a “base” Level 3 PRA?
- A number of supporting requirements include examples. Are the included examples helpful, or do they create confusion as to what is required?

PREPARATION OF TECHNICAL INQUIRIES TO THE JOINT COMMITTEE ON NUCLEAR RISK MANAGEMENT

INTRODUCTION

NOTE FOR TRIAL USE: The text of this section describes the technical inquiry process for approved standards. However, during the trial use period, users are encouraged to provide feedback, ask questions, and interact with the Level 3 Working Group on either a formal or informal basis. Such feedback may be provided via the Secretary of the Joint Committee on Nuclear Risk Management, as noted below.

The ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM) will consider written requests for the interpretation and revision of risk management standards and the development of new requirements as dictated by technological development. JCNRM's activities in this latter regard are strictly limited to interpretations of the requirements or to the consideration of revisions to the requirements on the basis of new data or technology. As a matter of published policy, The American Society of Mechanical Engineers (ASME) does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity, and, accordingly, inquiries requiring such considerations will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the standard's requirements. If, based on the inquiry information submitted, it is the opinion of the JCNRM that the inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

To be considered, inquiries will require sufficient information for JCNRM to fully understand the request.

INQUIRY FORMAT

Inquiries shall be limited strictly to interpretations of the requirements or to the consideration of revisions to the present requirements on the basis of new data or technology. Inquiries shall be submitted in the following format:

(a) *Scope.* The inquiry shall involve a single requirement or closely related requirements. An inquiry letter concerning unrelated subjects will be returned;

(b) *Background.* State the purpose of the inquiry, which would be either to obtain an interpretation of the standard's requirement or to propose consideration of a revision to the present requirements. Concisely provide the information needed for JCNRM's understanding of the inquiry (with sketches as necessary), being sure to include references to the applicable standard edition, addenda, part, appendix, paragraph, figure, or table;

(c) *Inquiry Structure.* The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. This inquiry statement should be technically and editorially correct;

(d) *Proposed Reply.* State what it is believed that the standard requires. If, in the inquirer's opinion, a revision to the standard is needed, recommended wording shall be provided;

(e) *Typewritten/Handwritten.* The inquiry shall be submitted in typewritten form; however, legible, handwritten inquiries will be considered;

(f) *Inquirer Information.* The inquiry shall include the name, telephone number, and mailing address of the inquirer;

(g) *Submission.* The inquiry shall be submitted to the following address: Secretary, Joint Committee on Nuclear Risk Management, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

USER RESPONSIBILITY

Users of this Standard are cautioned that they are responsible for all technical assumptions inherent in the use of PRA models, computer programs, and analysis performed to meet the requirements of this Standard.

CORRESPONDENCE

Suggestions for improvements to the Standard or inclusion of additional topics shall be sent to the following address: Secretary, Joint Committee on Nuclear Risk Management, The American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

COMMITTEE ROSTERS

CONTRIBUTORS TO THE STANDARD FOR RADIOLOGICAL ACCIDENT OFFSITE CONSEQUENCE ANALYSIS (LEVEL 3 PRA) TO SUPPORT NUCLEAR INSTALLATION APPLICATIONS

(The following is a roster of the Joint Committee on Nuclear Risk Management at the time of the approval of this Standard.)

This Standard was processed and approved for release as a trial use and pilot application by the ASME/ANS Joint Committee on Nuclear Risk Management (JCNRM). Committee approval of the Standard does not necessarily imply that all committee members voted for its approval. At the time it approved this Standard, the JCNRM had the following members:

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The ASME/ANS RA-S-1.3 Working Group wishes to provide special appreciation and recognition of the hard work, knowledge, and insights provided by Jocelyn Mitchell who passed away during the latter stages of the Standard development. Her guidance, support, contributions, and continued encouragement were keys to completing this Standard. She helped the group maintain appropriate balance of technical requirements through her continual scrutiny of superfluous additions, which were in her words, "gilding the lily."

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STANDARD FOR RADIOLOGICAL ACCIDENT OFFSITE CONSEQUENCE ANALYSIS (LEVEL 3 PRA) TO SUPPORT NUCLEAR INSTALLATION APPLICATIONS

Section 1
Introduction

1.1 OBJECTIVE

This Standard sets forth requirements for the consequence analysis portion of probabilistic risk assessments (PRAs) used to support risk-informed decisions for accidents involving the release of radioactive materials into the atmosphere. It is expected that the primary use of this Standard would be in support of nuclear power plants, although it could support broader applications. In these cases, supplemental requirements may be needed to ensure technical adequacy. This portion of a PRA is typically known as a Level 3 analysis.

1.2 COORDINATION WITH OTHER PROBABILISTIC RISK ASSESSMENT STANDARDS

This Standard was developed based on the body of knowledge and experience accumulated through the development and application of the American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) RA-Sb-2013, “Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” [1] and the Level 2 PRA Standard, ASME/ANS RA-S-1.2-2014, “Severe Accident Progression and Radiological Release (Level 2) PRA Standard for Nuclear Power Plant Applications for Light Water Reactors (LWRs),” [2] which has been approved for trial use and pilot application. This Standard, however, is not dependent upon these other PRA standards, although it is noted that the development of the final risk estimation for reactors will be based on combining the results of the Level 1 and Level 2 (Level 1/2) PRA portions (e.g., release frequencies, release characterizations) and the results of the consequence analysis.

1.3 PURPOSE AND SCOPE

Consequence analysis assesses the effect of releases of radionuclides on the surrounding population and the environment. This Standard only includes limited treatment of the impact on doses of the release of radioactive materials that could reach liquid pathways (i.e., due to deposition onto land and bodies of water).

To date, there have been few consequence assessments dealing with liquid releases from nuclear facilities. Such releases would include releases in liquid form into rivers, lakes, estuaries, and oceans. In addition, releases could reach aquifers via transport through geological media. The rationale for not treating liquid releases in consequence analyses has typically been due to adequate time available for interdiction of foodstuffs and relocation. Therefore, this Standard does not address transport through geological media and into aquifers or releases of radioactive material directly into surface water bodies.

Consequence modeling can therefore be defined as a set of calculations of the ranges of potential adverse impacts (in terms of probabilities of occurrence and magnitudes) that would follow from the dose received by humans due to a release of radionuclides. These adverse impacts, commonly referred to as "public risks," include (1) early fatalities, (2) latent cancer fatalities, (3) early injuries, and (4) non-fatal cancers. In addition, adverse impacts can occur due to contamination of property, land, and surface water. Consequence analyses may include assessments of the economic impact of dose avoidance strategies, such as relocation of population, land and structure decontamination, and interdiction of foodstuffs.

Consequence modeling provides the means for relating these risks to the characteristics of the radioactive release and has many actual or potential applications including the following examples:

(a) risk evaluation, generic or site-specific, individual or the general population
(b) environmental impact assessment
(c) rulemaking and regulatory procedures
(d) emergency response
(e) development of criteria for the acceptability of risk
(f) instrumentation needs and dose assessment
(g) facility siting
(h) comparison with safety goals evaluation
(i) evaluation of alternative design features (e.g., severe accident mitigation alternatives (SAMAs) analysis)
(j) cost-benefit analyses

A Level 3 analysis incorporates information including demography, emergency planning, physical properties of radionuclides, meteorology, atmospheric dispersion and transport, size of nearby structures, health physics, and other disciplines. Use of this information is detailed in this Standard.

While the primary use of this Level 3 PRA Standard is most likely to be for LWRs, the methodology is generally applicable to any type of radioactive material released to the atmosphere for which the release characteristics can be defined. It is recognized, however, that there may be specific applications where the source term phenomenology and atmospheric dispersion are complex. Examples of potential analyses may include

(a) releases of dense and/or reactive gases (e.g., UF6) that can have complex release and transport characteristics;
(b) releases of tritium or carbon-14, which behave differently in the environment (e.g., deposition followed by re-emission); or
(c) energetic releases (i.e., explosions where momentum effects might be significant).

Although there may be available analytical tools for determining such consequences, the Supporting Requirements (SRs) in this Standard may not fully address such phenomenology. Section 3 of this Standard outlines a process by which the completeness of the requirements is assessed and supplemented to meet analytical requirements. This includes the selection of appropriate models. Additionally, Section 7 of this Standard provides peer review requirements to ensure technical adequacy of the analysis.

1.4 STRUCTURE FOR LEVEL 3 REQUIREMENTS

1.4.1 Level 3 Technical Elements

The technical requirements for the Level 3 analysis are organized by their respective technical elements. These technical elements define the scope of a Level 3 analysis. Sections 4 and 5 discuss these technical elements in detail.

1.4.2 High Level Requirements

A set of objectives and high level requirements (HLRs) is provided for each technical element in the Technical Requirements (Section 4 of this Standard). The HLRs set forth the minimum requirements to assess the technical adequacy of a Level 3 analysis, independent of an application. The HLRs are defined in general terms and present the top-level logic for the derivation of more detailed SRs.

1.4.3 Supporting Requirements (SRs)

A set of SRs is provided for each HLR in Sections 4 and 5. Multiple HLRs are defined for each technical element.

This Standard is intended to support a wide range of applications that require a corresponding range of Level 3 analysis capabilities. Applications vary with respect to which risk metrics are employed, which decision criteria are used, the extent of reliance on the results to support a decision, and the degree of resolution required for the factors that determine the risk significance of the subject of the decision. In developing the different portions of the Level 3 PRA model, it is recognized that not every technical element (e.g., atmospheric transport and dispersion model) will be or needs to be developed to the same degree of site specificity or the same degree of realism.

1.4.4 Capability Categories

The types of risk-informed PRA applications contemplated under this Standard are very broad and include applications related to design, emergency response, meteorological programs, licensing, and many other disciplines. Both regulatory risk-informed applications and applications not involving U.S. Nuclear Regulatory Commission (NRC) regulations are contemplated.

Although the range of capabilities required for each portion of the PRA to support an application falls on a continuum, three levels are defined and labeled either Capability Category I, II, or III, so that requirements can be developed and presented in a manageable way. Table 1-1 describes, for two principal attributes of PRA, the bases for defining the Capability Categories. This table was used to develop the SRs for each HLR. It is noted that Table 1-1 in this Standard excludes the attribute of scope and level of detail associated with plant design, operation, and maintenance used in the analogous table in the ASME/ANS PRA Standard (RA-Sb-2013 [1]), because this attribute is not generally applicable to Level 3 analyses. The two attributes of site specificity and realism provide adequate means to differentiate Capability Categories.

The intent of the delineation of the Capability Categories within the SRs is generally that the degree of site specificity and the degree of realism increases from Capability Category I to Capability Category III. However, the Capability Categories are not based on the level of conservatism (i.e., tendency to overestimate risk due to simplifications in the PRA) in a particular aspect of the analysis. The level of conservatism may decrease as the Capability Category increases and more detail and more realism are introduced into the analysis. However, this is not true for all requirements, and this should not be assumed.

For example, traditionally the effects of rainfall on wet deposition were generally not included in simplified analyses that are analogous to Capability Category I. This omission may be non-conservative. On the other hand, accounting for wet deposition, as would be required in Capability Categories II and III, is both more realistic and more conservative.

The boundaries between these Capability Categories can only be defined in a general sense. When a comparison is made between the capabilities of any given Level 3 analysis and the SRs of this Standard, it is expected that the capabilities within technical elements will not necessarily all fall within the same Capability Category, but rather will be distributed among all three Capability Categories. It should be noted that there may be technical elements, or portions of the technical elements, that fail to meet the SRs for any of these Capability Categories. While all portions of the analysis need not have the same capability, the analytical methods should be coherent. The SRs have been written so that, within a Capability Category, the interfaces between portions of the PRA are coherent.

When a specific application is undertaken, professional judgment is needed to determine which Capability Category is needed for each portion of the PRA, and hence which SRs apply to the applications.

For each Capability Category, the SRs define the minimum requirements necessary to meet that Capability Category. Some SRs apply to only one Capability Category and some extend across two or three Capability Categories. When an SR spans multiple Capability Categories, it applies equally to each Capability Category. When necessary, the differentiation between Capability Categories is made in other associated SRs. The interpretation of an SR that spans multiple Capability Categories is stated in Table 1-2.

It is intended that by meeting all the SRs under a given HLR, a PRA will meet that HLR. The technical requirements section of each respective section of this Standard also specifies the required documentation to facilitate PRA applications, upgrades, and peer review.

The SRs specify what to do rather than how to do it, and, in that sense, specific methods for satisfying the requirements are not prescribed. Nevertheless, certain established methods were contemplated during the development of these requirements. Alternative methods and the approaches to the requirements of this Standard may be used, if they provide results that are equivalent or superior to the methods usually used, and they meet the HLRs and SRs presented in this Standard. The use of any particular method for meeting an SR shall be documented and shall be subject to review by the peer review process described in Section 7.

1.5 THE NATURE OF THE REQUIREMENTS

The HLRs contained herein are phrased in the usual language of standards, namely, the language of “shall.”

Action Verbs: SRs are phrased in action-verb form. Whenever an action verb is used, the requirement is to be understood as if the “shall” form were used. Examples of action verbs used in this Standard include USE, DOCUMENT, REVIEW, ESTIMATE, CALCULATE, INCLUDE.

In many places, the SRs mention sources of data as examples of acceptable input. The plain meaning of this wording should be clear, namely, that such sources are acceptable to meet this Standard. The intent of any requirement that uses this language is to be permissive, meaning that the analysis team can use another source of data without prejudice. The analysis can use another source of data that provides a comparable level of relevance and accuracy. Whenever an alternative to the acceptable data source is selected, it is understood that the peer review team will pay particular attention to this topic.

All notes associated with individual SRs are nonmandatory.

1.6 RISK ASSESSMENT APPLICATION PROCESS: SECTION 3

Section 3 of this Standard describes requirements for a process that shall be used to determine the capability of a Level 3 analysis to support various applications. The use of a Level 3 analysis will be different from application to application. This Standard, which is application non-specific, is concerned only with the capability of the analysis to support risk-informed decision-making. For a specific application, the technical capabilities may be evaluated against this Standard, requirement by requirement on an as-needed basis to support the application, rather than by evaluating whether the Level 3 analysis as a whole has all of the appropriate technical capabilities to meet this Standard.

1.7 LEVEL 3 CONSEQUENCE ANALYSIS TECHNICAL REQUIREMENTS: SECTION 4

Section 4 provides specific SRs for each HLR for each technical element defined for a Level 3 analysis.

1.8 RISK ESTIMATION (RI): SECTION 5

Section 5 provides requirements that integrate Level 3 analyses with the results from the Level 1/2 analyses to obtain a characterization of the overall risk including the determination of uncertainty.

1.9 CONFIGURATION CONTROL: SECTION 6

Section 6 provides requirements for configuration control of a Level 3 analysis (i.e., maintaining and upgrading a site/plant-specific analysis) to a degree sufficient to support an application for which it may be used.

1.10 PEER REVIEW: SECTION 7

Section 7 of this Standard provides the general requirements for a peer review to determine if the methodology and its implementation meet the SRs of the HLRs for each technical element in this Standard.

1.11 DOCUMENTATION REQUIREMENTS

Specific documentation requirements are defined in detail in each technical element in Sections 4 and 5.

1.12 USE OF EXPERT JUDGMENT

This paragraph provides requirements for the use of expert judgment outside of the Level 3 analysis team to resolve a specific technical issue. Guidance from NUREG/CR-6372 [3] and NUREG-1563 [4] may be used to meet the requirements in this paragraph. Other approaches or a combination of these may also be used. A review of expert aggregation methods, the different types of consensus, and issues with resolving disagreements among experts can be found in Appendix J of NUREG/CR-6372 [3]. A series of NUREG documents (i.e., NUREG/CR-6244 [5], NUREG/CR-6523 [6], NUREG/CR-6526 [7], NUREG/CR-6545 [8], NUREG/CR-6555 [9], and NUREG/CR-6571 [10]) summarizes a joint NRC and Commission of European Communities study pertaining to expert judgment for a variety of technical issues related to consequence analysis. This series documents both the process and the results of the expert elicitations performed.

1.12.1 Objective of Using Expert Judgment

The Level 3 analysis team shall explicitly and clearly define the objective of the information that is being sought through the use of outside expert judgment and shall explain this objective and the intended use of the information to the expert(s).

1.12.2 Identification of the Technical Issue

The Level 3 analysis team shall explicitly and clearly define the specific technical issue(s) to be addressed by the expert(s).

1.12.3 Determination of the Need for Outside Expert Judgment

The Level 3 analysis team may elect to resolve a technical issue using its own expert judgment or the judgment of others within their organization. The Level 3 analysis team shall use outside experts when the needed expertise on the given technical issue is not available within the analysis team or within the team's organization. The Level 3 analysis team should use outside experts, even when such expertise is available inside, if there is a need to obtain broader perspectives and corroborate various facets of the analyses for any of the following or related reasons:

- *(a)* Complex experimental data exist that the analysts know have been interpreted differently by different outside experts.
- *(b)* More than one conceptual model exists for interpreting the technical issue, and judgment is needed as to the applicability of the different models.
- *(c)* Judgments are required to assess whether assumptions or calculations are appropriately realistic and/or representative for the application.
- *(d)* Uncertainties are large and significant, and judgments of outside technical experts are useful in illuminating the specific issue.

1.12.4 Identification of Expert Judgment Process

The Level 3 analysis team shall determine

- *(a)* the degree of importance and the level of complexity of the issue, and
- *(b)* whether the process will use a single entity (individual, team, company, etc.) that will act as an evaluator and integrator and will be responsible for developing the community distribution or will use a panel of expert evaluators and a facilitator/integrator.

The facilitator/integrator shall be responsible for aggregating the judgments and community distributions of the panel of experts so as to develop the composite distribution of the informed technical community.

1.12.5 Identification and Selection of Evaluator Experts

The Level 3 analysis team shall identify one or more experts capable of evaluating the relative credibility of multiple alternative hypotheses to explain the available information. These experts shall evaluate all potential hypotheses and bases of inputs from the literature and from proponents and resource experts and shall provide

- *(a)* their own input, and
- *(b)* their representation of the community distribution.

1.12.6 Identification and Selection of Technical Issue Experts

If needed, the Level 3 analysis team shall also identify other technical issue experts, such as

(a) experts who advocate particular hypotheses or technical positions (e.g., individual(s) who evaluates data and develops a particular hypothesis to explain it); and,

(b) technical experts with knowledge of a particular technical area of relevance to the issue.

1.12.7 Responsibility for the Expert Judgment

The Level 3 analysis team shall assign responsibility for the resulting judgments, either to an integrator or shared with the experts. Each individual expert shall accept responsibility for his individual judgments and interpretations.

1.13 PROCESS CHECK

Analyses, calculations, and/or data used directly in the Level 3 analysis (e.g., meteorological data) or used to support the Level 3 analysis (e.g., Level 2 input on releases characterization) shall be reviewed by knowledgeable individuals who did not perform those analyses or calculations. Documentation of this review may take the form of handwritten comments, signatures, or initials on the analyses/calculations, formal sign-offs, or equivalent methods.

1.14 COMPUTER CODES: APPENDIX A

Appendix A provides a summary of computer codes used for performing Level 3 PRA consequence analysis and is provided for information purposes in consideration of code selection. Appendix A is nonmandatory.

Table 1-1 Bases for Level 3 Capability Categories

Attributes	Capability Category I	Capability Category II	Capability Category III
1. Site specificity: the degree to which site/plant-specific information is incorporated, such that the existing conditions are addressed.	Use of generic data/models is acceptable.	Use of site/release-specific data/models for the local and regional features will have a significant impact on the results.	Use of site/release-specific data/models for all features will have significant or even moderate impact on the results.
2. Model realism: the degree to which realism is incorporated in the inputs and model	Departures from modeling realism will have moderate impact on the conclusions and risk insights as supported by good practices [see Note (1)].	Departures from modeling realism will have small impact on the conclusions and risk insights as supported by good practices [see Note (1)].	Departures from modeling realism will have negligible impact on the conclusions and risk insights as supported by good practices [see Note (1)].

NOTE:

(1) Differentiation from moderate, to small, to negligible is determined by the extent to which the impact on the conclusions and risk insights could affect a decision under consideration. This differentiation recognizes that the Level 3 analysis would generally not be the sole input to a decision. A moderate impact implies that the impact (of the departure from realism) is of sufficient size that it is likely that a decision could be affected; a small impact implies that it is unlikely that a decision could be affected, and a negligible impact implies that a decision would not be affected.

Table 1-2 Interpretation of Supporting Requirements

SR Spans	Peer Review Finding	Interpretation of the Supporting Requirement
All Three Capability Categories (I/II/III)	Meets SR	Capable of supporting applications in all Capability Category
	Does not meet SR	Does not meet minimum standard
Single Capability Category (I, II, or III)	Meets Individual SR	Capable of supporting applications requiring that Capability Category or lower
	Does not meet any SR	Does not meet minimum standard
Lower Two Capability Categories (I/II)	Meets SR for Capability Category I/II	Capable of supporting applications requiring Capability Category I or II
	Meets SR for Capability Category III	Capable of supporting applications in all Capability Category
	Does not meet SR	Does not meet minimum standard
Upper Two Capability Categories (II/III)	Meets SR for Capability Category II/III	Capable of supporting applications in all Capability Category
	Meets SR for Capability Category I	Capable of supporting applications requiring Capability Category I
	Does not meet SR	Does not meet minimum standard

Section 2
Acronyms and Definitions

2.1 ACRONYMS AND ABREVIATIONS

AD: atmospheric transport and dispersion

AMAD: activity median aerodynamic diameter

ANS: American Nuclear Society

ANSI: American National Standards Institute

ASME: American Society of Mechanical Engineers

ATD: atmospheric transport and dispersion

BEIR: Committee on the Biological Effects of Ionizing Radiation

Bq: Becquerel

CCDF: complementary cumulative distribution function

Ci: Curie

CPI: consumer price index

DCF: dose conversion factor

DO: dosimetry

EC: economic factors

EPA: U.S. Environmental Protection Agency

EPZ: emergency planning zone

ETE: evacuation time estimate

FGR: federal guidance report

GDP: gross domestic product

HE: health effects

HLR: high level requirement

ICRP: International Commission on Radiological Protection

KI: potassium iodide

L1: Level 1

L2: Level 2

L3: Level 3

LHS: Latin hypercube sampling

LIDAR: light detection and ranging

LNT: linear non-threshold

LWR: light water reactor

ME: meteorological data

NRC: U.S. Nuclear Regulatory Commission

NUREG: a class of technical documents issued by the Nuclear Regulatory Commission

PA: protective-action parameters and other site data

PBL: planetary boundary layer

PRA: probabilistic risk assessment

QHO: quantitative health objective

QT: Conditional consequence quantification and reporting

RE: radionuclide release characterization for Level 3

rem: roentgen equivalent man

RI: risk estimation

SAMA: severe accident mitigation alternative

SAMDA: severe accident mitigation design alternative

SI: international system (of measurement)

SODAR: sonic detection and ranging

SR: supporting requirement

SSC: Structures, Systems, and Components

STAR: stability array

Sv: Sievert

TEDE: total effective dose equivalent (also known as effective dose)

2.2 DEFINITION OF TERMS

activity median aerodynamic diameter (AMAD): The median diameter, based on activity rather than mass, of a particle with unit density that has the same terminal velocity when settling in air as the particle of interest.

assumption: A decision or judgment that is made in the development of the PRA model. An assumption is either related to a source of model uncertainty or is related to scope or level of detail. An assumption related to a model uncertainty is made with the knowledge that a different reasonable alternative assumption exists. A reasonable alternative assumption is one that has broad acceptance within the technical community and for which the technical basis for consideration is at least as sound as that of the assumption being made. An assumption related to scope or level of detail is one that is made for modeling convenience. An assumption is labeled “key” when it may influence (i.e., have the potential to change) the decision being made. Therefore, a key assumption is identified in the context of an application.

atmospheric transport and dispersion (ATD): The process by which material that has been released from its place of confinement moves through and spreads upon release to the atmosphere.

Becquerel (Bq): A unit of radioactivity in international system (SI). It is equal to one disintegration per second.

cohort: A subset of the offsite population that mobilizes for, or moves differently from others, in the modeling of emergency response actions.

commitment period: Length of time used to calculate the dose accrued to individuals from intake of radioactive sources (e.g., ingestion, inhalation).

complementary cumulative distribution function (CCDF): Plot of consequence parameter being calculated against its probability or frequency of exceedance.

condemnation: Permanent denial of the use of land or buildings following contamination by radioactive material released from a facility.

convective eddy formation: Movement of air parcels under the influence of density differences (e.g., buoyancy).

consequence: The effects of a radiological release to the atmosphere that can include doses to an individual or population, health effects or individual risk of health effects, contaminated land areas, and economic costs.

Curie (Ci): Amount of radioactivity equal to 3.7×10^{10} disintegrations per second.

delta-T: Vertical temperature difference in the atmosphere that is used to type atmospheric turbulence.

disintegration: Process of radioactive decay releasing an energetic photon or particle.

dose conversion factor: A parameter describing the energy from particles and waves deposited in an organ, tissue, or body.

dosimetry: Process of determining dose from exposure to radiation.

early fatalities: Deaths from the acute effects of radiation that may occur within a few months of the exposure.

economic factors: Expressions of the costs of various aspects of actions following a release of material to the environment. For instance, costs can be incurred for evacuation or relocation of population, decontamination of land or buildings, interdiction of foodstuffs, or condemnation of land.

emergency planning zone (EPZ): Two areas surrounding a production or utilization facility. For the U.S., one is about 16.09 km (10 miles) in diameter (called the plume exposure pathway EPZ), where detailed planning to enhance the health and safety of the close-in population is required for protection from plume exposure, and the second is about 80.45 km (50 miles) in diameter (called the ingestion exposure pathway EPZ) where preparation to interdict or condemn food and water for protection of the population is required.

emergency response: Actions taken by offsite populations to cope with the health and safety aspects of an incident at a production or utilization facility.

evacuation: A response to an emergency at a facility involving removal of a selected portion of the population surrounding the facility. Evacuation is usually described in the emergency plans of a facility for the close-in population within the plume exposure pathway EPZ [usually about 16 km (10-miles) from the site] and is often planned to be accomplished in advance of the release of material as a means of dose avoidance.

exposure period: Length of time used to calculate the dose accrued to exposed individuals from external radioactive sources (e.g., cloudshine, groundshine).

facility: Any structure/device from which a source of radioactive material may be released into the atmosphere.

fission: Process whereby an atom is separated into two or more new atoms of different material accompanied by release of energy.

fission product release: Release of radionuclides to the environment.

Gaussian model: See Gaussian plume model below.

Gaussian plume model: A one-dimensional model for ATD that assumes that a plume moves downwind at the speed of the wind. Dispersion actually takes place in three dimensions (i.e., the plume broadens in the crosswind direction and grows taller in the vertical direction as it is transported downwind), based on assumed functional descriptions.

gradient transfer model: First-order closure model based on K-theory, of which the Gaussian model is a solution.

halogens: Five non-metallic elements (i.e., fluorine, chlorine, bromine, iodine, and astatine) in Group 17 of the periodic table. Radionuclide halogens include both vapor and aerosol (particle) forms.

health effects: Impacts on populations exposed to releases of radioactive material. Health effects often used as metrics include early fatalities, latent cancer fatalities, and individual risk of both measures. Dose or effective dose can also sometimes be used as metrics, although neither one is strictly a health effect.

higher-order closure models: An approximation to turbulence that retains prognostic equations for mean variables (e.g., potential temperature and wind), as well as for some of the higher-order statistics including variance (e.g., turbulence kinetic energy or temperature variance) or covariance (e.g., kinematic fluxes, such as for heat and momentum).

interdiction: Temporary denial of the use of land or buildings for some time following contamination by radioactive material released from a facility. It also is associated with the collection of contaminated food prior to ingestion by the general public.

ionizing radiation: Subatomic particles or electromagnetic waves that are energetic enough to detach electrons from atoms or molecules and producing radiation capable of causing damage to cells.

isotope: One of possible several forms of an atom of an element having different numbers of neutrons.

keyhole evacuation: Evacuation in a 360-degree circle for a specific distance and in the downwind direction in which plume is expected to travel.

land use: Parameters used to determine the doses to the public consuming food and residing in areas where radioactive materials have deposited.

latent cancer fatalities: Deaths from cancer that were caused by chronic effects of radiation exposure; latent cancer fatalities may occur years after the exposure.

Latin hypercube sampling (LHS): A method of stratified sampling developed to generate a distribution of plausible collections of parameter values from a multi-dimensional distribution. The sampling method is often applied in uncertainty analysis to obtain a representative sample.

Level 1 (L1) analysis: Identification and quantification of the sequence of events leading to the onset of core damage.

Level 2 (L2) analysis: Evaluation of containment/confinement response to severe accident challenges and quantification of the mechanisms, amounts, and probabilities of subsequent radioactive material releases to the environment.

Level 1/2: A shorthand reference used in this Standard to refer to the Level 1 and Level 2 analyses, including analyses where Level 1 and Level 2 analyses are developed in a combined manner (e.g., gas cooled reactors) or equivalent analyses for other facilities (e.g., fuel cycle facility, other non-reactor nuclear facilities) that provide a source term and frequency.

Level 1/2/3: A shorthand reference used in this Standard to refer to the Level 1, Level 2, and Level 3 analyses.

Level 3 (L3) analysis: Estimation of the consequences of the release to the environment from radioactive materials, as identified in the Level 1/2 analyses.

light detection and ranging (LIDAR): An optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

linear non-threshold (theory) (LNT): A dose-response model that assumes induction of cancer proportional to dose, no matter how small the dose.

may: Used to state an option to be implemented at the user’s discretion.

Monin-Obukhov similarity: A relationship describing the vertical behavior of non-dimensional mean flow and turbulence properties within the atmospheric surface layer (the lowest 10% or so of the atmospheric planetary boundary layer).

Monte Carlo method: A statistical method for random, unbiased, sampling of a parameter.

neurovascular symptoms: Effects arising from the impact of ionizing radiation on the nerves and the blood vessels in the body.

Pasquill-Gifford: A technique to type turbulence into discrete atmospheric dispersion categories.

plant: A general term used to refer to a nuclear power facility (e.g., “plant” could be used to refer to a single unit or multi-unit site).

plume: An amount of material continually released over a period of time.

point estimate: Estimate of a parameter in the form of a single number.

population dose: The total dose summed over the population exposed to the radiological release expressed in person-rem or person-Sievert.

puff: An amount of material released over a short, almost instantaneous, period of time.

probabilistic risk assessment (PRA): A qualitative and quantitative assessment of the risk associated with plant operation and maintenance that is measured in terms of frequency of occurrence of risk metrics, such as core damage or a radioactive material release and its effects on the health of the public [also referred to as a probabilistic safety assessment (PSA)].

PRA maintenance: The update of the PRA models to reflect plant changes, such as modifications, procedure changes, new population data, or plant performance (data).

PRA upgrade: The incorporation into a PRA model of a new methodology or changes in scope or capability that impact the Level 3 analysis metrics. This could include items such as new source terms, new methods or parameters impacting atmospheric dispersion, etc.

probit: Probability unit function, defined as the inverse cumulative distribution function.

protective actions: Actions taken by the public to mitigate the impacts of radiological releases.

QHO risk metric: Quantitative health objectives of NRC's Safety Goal Policy Statement that define goals for the average individual risk of early fatality and latent cancer fatality arising from accidents at nuclear power plants.

radiation absorbed dose (rad): A unit of measure of radiation dose (in common units).

radionuclide: A radioactive isotope.

radiation: The energy in the form of particles or waves emitted from an atom as it decays.

release category: 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.

Richardson number: A dimensionless number that expresses the ratio of potential to kinetic energy.

risk: Probability and consequences of an event as expressed by the "risk triplet," which is the answer to the following three questions: (1) What can go wrong? (2) How likely is it? (3) What are the consequences if it occurs?

roentgen equivalent man (rem): Unit of measure of biological effect of radiation exposure.

sampling: A method of choosing a representative number or amount from a larger number or amount.

segmented plume model: A model in which the plume is separated into segments downwind that enable spatial and temporal changes in trajectory and dispersion.

severe accident: An accident that involves extensive core damage and fission product release into the reactor vessel and containment with potential release to the environment.

shadow evacuation: Voluntary evacuation by individuals outside the recommended evacuation zone, early or spontaneously.

shall: Used to state a mandatory requirement.

should: Used to state a recommendation.

sheltering: Response to an emergency at a facility involving the recommendation that part of the population surrounding the facility remain indoors with the windows closed for the time during which the plume of material is passing through the location.

shielding: Protection from radiation exposure afforded by a structure. Shielding for gamma shine from the passing cloud of material, for gamma shine from material deposited on the ground, or for inhalation of material are possible avenues of protection.

Sievert (Sv): A unit of measure of the biological effect of radiation exposure in SI units (1 Sv = 100 rem).

sigma-theta: Standard deviation of the wind direction measurements, which can be used to type atmospheric turbulence.

sigmoidal function: A function that is real-valued and differentiable having either a non-negative or non-positive first derivative and exactly one inflection point.

significant contributor: In the context of a Level 3 analysis conditional consequence results, a contributor to a consequence metric of interest that meaningfully influences the result. Three examples are the source term release magnitude, source term release timing, and the population distribution. In the context of risk results, an input or modeling choice that meaningfully influences (e.g., contributes more than 5% of the total) the risk metric of interest. One example is release category frequency.

sonic detection and ranging (SODAR): A meteorological instrument that measures the scattering of sound waves by atmospheric turbulence.

source of model uncertainty: A source is related to an issue in which there is no consensus approach or model, and where the choice of approach or model is known to have an effect on the consequence model (e.g., use of a new atmospheric dispersion model, radial evacuation vs. network evacuation). A source of model uncertainty is labeled “key” when it could impact the PRA results that are being used in a decision, and consequently may influence the decision being made. Therefore, a key source of model uncertainty is identified in the context of an application. This impact would need to be significant enough that it changes the degree to which the risk acceptance criteria are met, and therefore could potentially influence the decision.

source term: The characteristics of a radionuclide release at a particular location including the physical and chemical properties of released material, release magnitude, heat content (or energy) of the carrier fluid, location relative to local obstacles that would affect transport away from the release point, and the temporal variations in these parameters (e.g., time of release, release duration, etc.).

spatial interval: A portion of a plume (e.g., plume segment) with the same dispersion characteristics.

stability array method (STAR): U.S. Environmental Protection Agency (EPA) technique for typing atmospheric turbulence into discrete stability classes.

straight-line steady-state model: Gaussian model in which the release amount, wind speed, wind direction, and turbulence parameters are assumed to not vary with time.

technical element: A topic in this Standard for which HLRs and SRs are provided (e.g., meteorology, dosimetry, or health effects).

uncertainty: A representation of the confidence in the state of knowledge about the parameter values and models used in constructing the PRA.

warning time: Elapsed time from the order to evacuate until the start of the release.

Section 3
Risk Assessment Application Process

3.1 PURPOSE

This section describes required activities to establish the capability of a Level 3 analysis to support a particular risk-informed application. For a specific application, Level 3 analysis capabilities are evaluated in terms of Capability Categories for individual SRs rather than by specifying a single Capability Category for the whole Level 3 analysis. Depending on the application, the required Level 3 capabilities may vary over and within different technical elements of this Standard. The process is intended to be used with PRAs that have had a peer review that meets the requirements of the Peer Review Section 7 of this Standard. It is noted that the process outlined in this section is focused on the Level 3 portion of the PRA. Similar activities would likely be required for the Level 1 and Level 2 portions of the PRA, as outlined in other PRA standards.

Figure 3-1 shows a logical ordering for the process. Although the specified activities are required, their order of execution may vary. As shown in the dashed-line boxes, there are five stages to the process:

(a) ***Stage A: Establish application Capability Categories***. In Stage A, Level 1/2/3 PRA analysts determine the Standard SRs necessary for the application. The SRs relevant to the different portions of a Level 1/2/3 within the scope, across the technical elements, and possibly within each technical element may be required to have different Capability Categories to support the application, and some portions of a Level 1/2/3 may be irrelevant to the application.

(b) ***Stage B: Establish Level 1/2/3 PRA scope***. The relevant portions of a peer-reviewed Level 1/2/3 PRA are examined to determine whether the scope and level of detail are sufficient for the application. If the relevant portions are found lacking in one or more areas, the Level 1/2/3 PRA may be upgraded or supplemented by other analyses (i.e., Stage E).

(c) ***Stage C: Confirm Level 3 PRA SRs complete***. An evaluation is performed to determine whether the capability requirements for the SRs from the Standard for each relevant portion of the Level 3 PRA are sufficient to support the application. If not, the SRs may be augmented with supplementary requirements as described in Stage E.

(d) ***Stage D: Confirm Level 3 PRA SRs satisfied***. Each relevant portion of the Level 3 analysis is compared to the appropriate SRs in the Standard for the Capability Category needed to support the application, as determined in Stage A. It is determined whether the relevant portions of the Level 3 PRA have adequate capability, need upgrading to meet the appropriate set of SRs, or need supplementary analyses as described in Stage E.

(e) ***Stage E: Support application***. The relevant portions of the Level 3 analysis supplemented by the development of additional requirements and additional analyses (e.g., onsite impacts, releases to ground water), if necessary, are used to support the application. The development of supplemental requirements is outside the scope of this Standard.

The scope of the activities in Figure 3-1 determines how to evaluate the role of the Level 3 PRA in the application and how to determine which Capability Categories are needed for each portion of the Level 3 PRA to support an application. The criteria for developing additional requirements and judging the quality of any supplementary analyses that are performed in lieu of upgrading the Level 3 PRA to meet a desired Capability Category are outside the scope of this Standard.

Accordingly, to "meet this Standard" means that the portions of the Level 3 used in the application meet the HLRs and SRs for a specified set of Capability Categories. The determination of how the Level 3 PRA is used in the application and which Capability Categories are appropriate for each application are made on an application specific basis.

3.2 IDENTIFICATION OF APPLICATION AND DETERMINATION OF CAPABILITY CATEGORIES (STAGE A)

3.2.1 Identification of Application

It is assumed that the application has been defined by Level 1/2/3 analysts by

(a) evaluating the plant design or operational change being assessed and identifying the SSCs and plant activities affected by the proposed change,
(b) identifying the Level 1/2 PRA model scope and risk metrics needed to assess the proposed change, and
(c) identifying the Level 3 PRA model scope and risk metrics needed to assess the proposed change.

3.2.2 Determination of Capability Categories

The Technical Requirements section of each respective section of this Standard sets forth SRs for three Level 3 PRA Capability Categories whose attributes are described in Section 1.4.

For the application, determine the relative importance of each portion of the PRA. This determination dictates which Capability Category is needed for each SR for each portion of the Level 1/2 PRA (see Box 1 of Figure 3-1) and the Level 3 PRA (see Box 2 of Figure 3-1) to support the application. To determine these capabilities, an evaluation shall be performed of the application to assess the role of the different portions of the PRA to support that application including determining the relative importance of SRs to the application, identifying the portions relevant to the application, and, for each relevant portion, determining the Capability Category for each SR needed to support the application. This evaluation would likely be performed by different analysts for different portions of the PRA. When performing this evaluation, the following application attributes shall be considered:

(a) role of the PRA in the application and extent of reliance of the decision on the PRA results
(b) risk metrics to be used to support the application and associated decision criteria
(c) degree to which simplified methods for the PRA or in a given portion of the PRA would lead to inappropriately influencing the decisions made in the application, and approach(es) for accounting for this in the decision-making process
(d) degree of accuracy and evaluation of uncertainties and sensitivities required of the PRA results
(e) degree of confidence in the results that is required to support the decision

To facilitate this process for the PRA, the Level 3 analyst may need to

(a) obtain documentation from the Level 1 and Level 2 analysts in which, considering the proposed application, all necessary and sufficient parts of their respective analyses have been completed;
(b) obtain documentation from the Level 1 and Level 2 analysts that identify the Capability Categories for all necessary and sufficient analyses; and
(c) determine the Capability Category needed for each SR of the Level 3 analysis.

The Capability Categories and the bases for their determination shall be documented.

3.3 ASSESSMENT OF PRA FOR NECESSARY SCOPE, RESULTS, AND MODELS (STAGE B)

3.3.1 Necessary Scope and Risk Metrics

Determine if the Level 1/2/3 PRA provides the results needed to assess the application (see Box 3 of Figure 3-1). If some aspects of the PRA are insufficient to support the application, then upgrade them in accordance with the SRs in the Technical Requirements section of each respective section of this Standard (or applicable standard for Level 1/2) for its corresponding Capability Category (see Box 4 of Figure 3-1), or generate supplementary analyses (see Section 3.6).

If it is determined that the Level 1/2/3 PRA is sufficient, the bases for this determination shall be documented. Any upgrade of the PRA shall be performed and also documented.

3.3.2 Peer Review

The portions of a Level 3 PRA that are needed for an application shall have been reviewed pursuant to the requirements of Section 7, Peer Review. Similarly, the portions of the Level 1/2 PRA that are needed for the application shall have been reviewed pursuant to the requirements of the applicable PRA standard(s).

3.4 DETERMINATION OF THE STANDARD'S SCOPE AND LEVEL OF DETAIL (STAGE C)

Determine if the scope of coverage and level of detail of the SRs stated in the HLRs of each respective technical element of this Standard for the corresponding Capability Categories determined in Section 3.2.2 are sufficient to assess the application under consideration (see Box 5 of Figure 3-1).

If it is determined that the Standard lacks specific requirements, supplementary requirements may be developed and used (see Box 6 of Figure 3-1).

3.5 COMPARISON OF LEVEL 3 MODEL TO STANDARD (STAGE D)

Determine if each portion of the Level 3 PRA satisfies the SRs at the appropriate Capability Category needed to support the application (see Box 7 of Figure 3-1) as previously determined (see Box 2 of Figure 3-1). The results of the peer review may be used. If the Level 3 meets the SRs necessary for the application, the Level 3 is acceptable for the application being considered (see Box 9 of Figure 3-1). The bases for this determination shall be documented.

If the Level 3 PRA does not satisfy an SR for the appropriate Capability Category, then either upgrade the Level 3 PRA to address the corresponding SRs stated in the HLRs of each respective technical element of this Standard (see Box 8 of Figure 3-1) or generate supplementary analyses (see Section 3.6). Any upgrade of the Level 3 PRA shall be performed and documented.

3.6 ACCESSING THE RISK IMPLICATIONS (STAGE E)

3.6.1 Use of Supplementary Analyses

If the scope of either the Level 3 PRA or the Standard is insufficient, supplementary analyses or requirements may be used (see Box 11 of Figure 3-1). These supplementary analyses will depend on the particular application being considered but may involve deterministic methods and determinations made by an expert panel. They shall be documented.

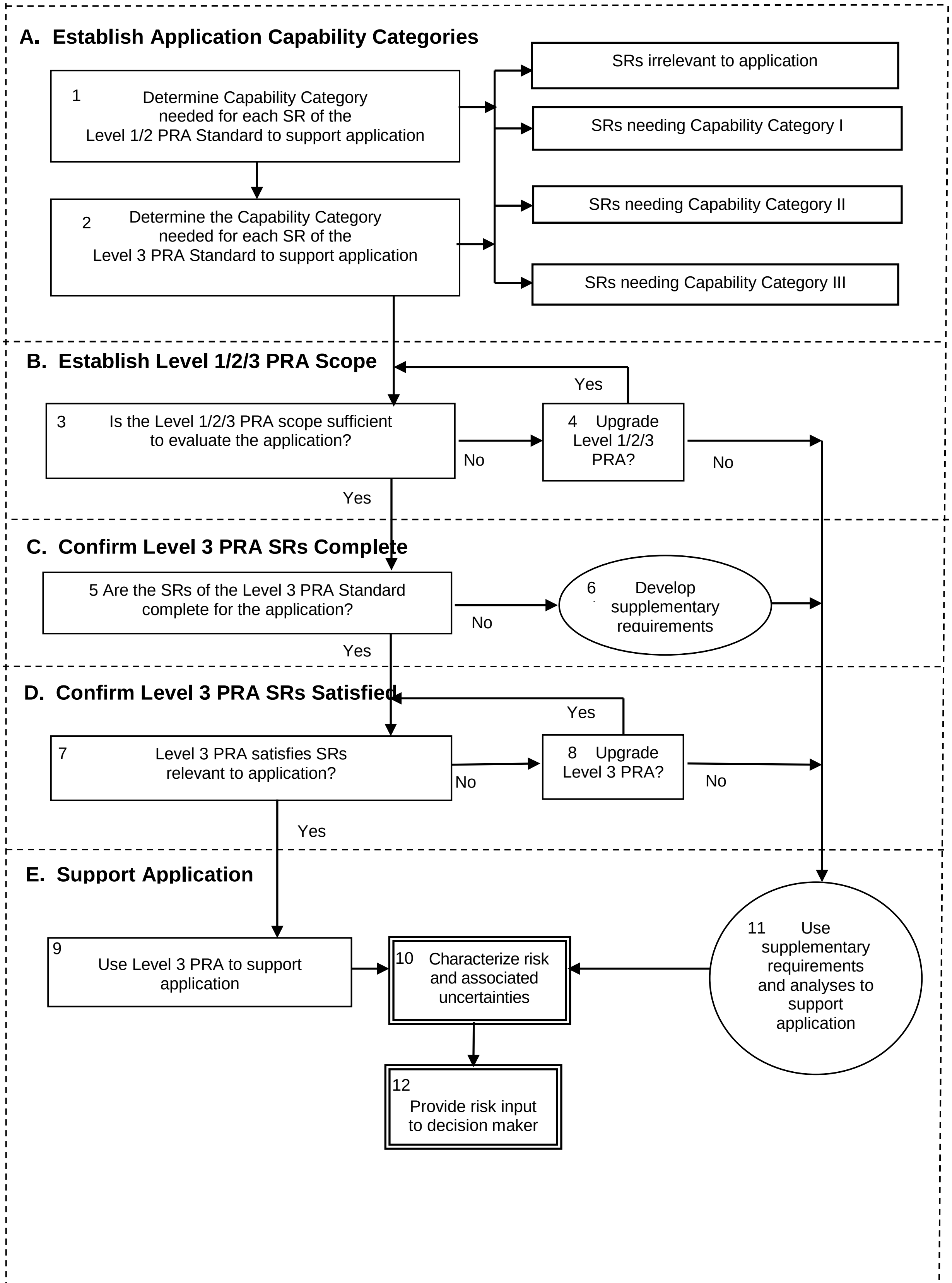
Supplementary requirements shall be drawn from other recognized codes or standards whose scopes complement that of this Standard and are applicable to the application but may be generated by an expert panel, if no such recognized code or standard can be identified.

3.6.2 Results of Supplementary Analyses

If it has been determined that the Level 3 PRA has sufficient capability, its results can be used to support the application (see Box 9 of Figure. 3-1). If not, the results of supplementary analyses, some of which may respond to supplementary requirements, can also be used to support the application (see Box 11 of Figure 3-1). Such supplementary analyses/ requirements are outside the scope of this Standard.

The risk contributors and associated uncertainties should be characterized for each technical element (see Box 10 of Figure 3-1). Once all significant parameters and uncertainties have been characterized, the risk information is provided as input to the decision maker (see Box 12 of Figure 3-1). The results of the Level 3 analysis are characterized in a combined fashion, as needed to support the application (see Section 5 of this Standard).

Fig. 3-1 Level 3 PRA Application Process Flowchart



Section 4
Level 3 Consequence Analysis
Technical Requirements

4.1 SCOPE

This section provides requirements for each of the technical elements that comprise the consequence part of a PRA. As discussed previously (see Section 1.3), the scope of a Level 3 analysis covered by this Standard includes determination of the consequences of releases of radioactive materials to the atmosphere. Limited treatment of the impact on doses of the release of radioactive materials that could reach liquid pathways is included (i.e., due to deposition onto land and bodies of water). This Standard does not address transport through geological media and into aquifers.

4.2 LEVEL 3 CONSEQUENCE MODEL

The Level 3 consequence model shall reflect the planned or actual as-built, as-operated nuclear installation or facility and its environs that are being analyzed.

4.3 TECHNICAL REQUIREMENTS: GENERAL

The requirements in Section 4 are organized by eight technical elements as follows:

- *(a)* radionuclide release characterization for Level 3 (RE)
- *(b)* protective action parameters and other site data (PA)
- *(c)* meteorological data (ME)
- *(d)* atmospheric transport and dispersion (AD)
- *(e)* dosimetry (DO)
- *(f)* health effects (HE)
- *(g)* economic factors (EC)
- *(h)* conditional consequence quantification and reporting (QT)

An additional technical element for risk estimation (RI) is presented in Section 5.

Objectives were established for each technical element used to characterize the respective scope of a consequence analysis. The objectives reflect substantial experience accumulated with consequence assessment development and usage. These objectives form the basis for development of the HLRs for each element that were used in turn to define the supporting requirements (SRs).

For each technical element that comprises a consequence analysis, this Standard includes both HLRs and SRs. The requirements in this Standard are intended to be used by both the PRA analysis team and the peer review team (see Section 7).

In defining the HLRs for each technical element, the goal was to derive, based on the objectives, an irreducible set of requirements, applicable to Level 3 analyses that support all levels of application, to guide the development of SRs. An additional goal was to derive a concise set of HLRs that capture all the important technical issues that were identified in the efforts to develop this Standard.

The HLRs generally address attributes of the PRA technical elements, such as

(a) scope and level of detail,
(b) model fidelity and realism,
(c) output or quantitative results (as applicable), and
(d) documentation.

SRs were developed to support the HLRs in the form of action statements for the various Capability Categories in the Standard. Therefore, there is a complete set of SRs provided to address the three Capability Categories (see Section 1.4.4).

4.4 PROBABILISTIC FRAMEWORK FOR CONSEQUENCE ANALYSES

The probabilistic framework for consequence analysis is treated in the discussions and requirements for each technical element. In addition, Section 5 provides guidance on risk estimation as it relates to presentation of the results. This shall include incorporation of the results of the Level 1/2 analyses (or equivalent).

By consequence, it is intended to mean the effects of a radiological release to the environment (i.e., atmosphere in this Standard) that can include, but not limited to, doses to an individual or population, health effects or individual risk of health effects, contaminated land areas, and economic costs.

4.5 RADIONUCLIDE RELEASE CHARACTERIZATION FOR LEVEL 3 (RE)

4.5.1 Introduction

The interfaces between radionuclide release (e.g., Level 1/2 analysis, radiological release from fuel cycle facility, etc.) and Level 3 analysis provide communication of site/plant information to facilitate the Level 3 analysis.

The radionuclide release interface defines the characteristics of the radionuclide release, including but not limited to the development of release categories, quantity of each radionuclide released to the environment, particle size distribution, the height and amount of energy associated with the release, the duration of the release, the time of the release after accident initiation, the warning time for evacuation, and the frequency of occurrence predicted for the release category.

4.5.2 Objectives

The objectives of the radionuclide release characterization process are to

(a) ensure that all release information required for the Level 3 analysis is provided in suitable form,
(b) ensure that the release categories have been clearly defined for use in the consequence analysis,
(c) provide clear traceability of the release categories used in the consequence analysis back to the radionuclide release analysis performed in the Level 1/2 analysis, and
(d) ensure that initiating event and sequence information from the Level 1/2 analysis that could impact the Level 3 analysis is provided.

4.5.3 High Level Requirements

The HLRs for transition from Level 2 analysis releases to Level 3 consequence analysis are provided in Table 4.5.3-1.

Table 4.5.3-1 High Level Requirements (HLRs) for Radionuclide Release Characterization for Level 3 (RE)

Designator	Requirement
HLR-RE-A	The radionuclide release(s) shall be characterized so as to support the offsite consequence analysis.
HLR-RE-B	Documentation of radionuclide release characterization shall be consistent with the applicable supporting requirements.

Table 4.5.3-1(a) Supporting Requirements (SRs) for HLR-RE-A

The radionuclide release(s) shall be characterized so as to support the offsite consequence analysis.

Index No. RE-A	Capability Category I	Capability Category II	Capability Category III
RE-A1 Release Category Definitions	USE release category definitions based on generic Level 1/2 analysis. ENSURE the release category definitions address the spectrum of releases (e.g., for nuclear power plants, the spectrum would include releases from breaks outside containment to releases from sequences ending with an intact containment).	USE release category definitions based on facility-specific Level 1/2 analysis. ENSURE that the release category definitions from the Level 1/2 analysis address the spectrum of releases (e.g., for nuclear power plants, the spectrum would include releases from breaks outside containment to releases from sequences ending with an intact containment).	
RE-A2 Binning Release Categories	USE available release category binning scheme from the Level 1/2 analysis.	USE a release category binning scheme that differentiates the release categories based on the various attributes listed in RE-A4 through RE-A10.	
RE-A3 Multiple Plumes	DEVELOP a single plume for each release category.	DEVELOP multiple plumes for each release category (e.g., to reflect significant changes in the source term as a function of time, to capture meteorological changes).	DEVELOP multiple plumes for each release category at the same resolution as the underlying meteorological data (e.g., to reflect significant changes in the source term as a function of time, to capture meteorological changes).
RE-A4 Release Quantities	ESTIMATE release fractions for each radioisotope group for each release category based on generic data. Alternatively, ESTIMATE quantities of each isotope for each release category based on generic data.	ESTIMATE release fractions for each radioisotope group and for each plume of each release category based on a facility-specific analysis. Alternatively, ESTIMATE quantities of each isotope for each plume of each release category based on a facility-specific analysis.	

Table 4.5.3-1(a) Supporting Requirements (SRs) for HLR-RE-A (Cont'd)

The radionuclide release(s) shall be characterized so as to support the offsite consequence analysis.

Index No. RE-A	Capability Category I	Capability Category II	Capability Category III
RE-A5 Isotopic Selection	SELECT the source term isotopes to include all that can result in significant doses and resultant health effects under accident conditions [see Note (1)].		
RE-A6 Radionuclide Inventory	If release fractions are used (per RE-A4), ESTIMATE the inventory of each radionuclide at time of accident initiation based on generic analysis (e.g., non-site-specific inventory data). It is acceptable to make adjustments to the inventory estimate (e.g., an inventory scale factor to reflect a different reactor power).	If release fractions are used (per RE-A4), ESTIMATE the inventory of each radionuclide at the time of accident initiation based on facility-specific inventory analysis that addresses inventory specific issues (e.g., burn-up for a nuclear power plant). It is acceptable to make small adjustments to the inventory estimate (e.g., an inventory scale factor to address a small power uprate).	
RE-A7 Release Timing	ESTIMATE the release timing (time of release and duration of release) for each release category based on generic analysis.	ESTIMATE the release timing (time of release and duration of release) for each plume of each release category based on a facility-specific analysis.	
RE-A8 Warning Time	ESTIMATE the warning time for protective actions for each release category based on generic analysis.	ESTIMATE the warning time for protective actions for each release category based on a facility-specific analysis (e.g., based on time of the General Emergency declaration by the site per the site emergency procedures Emergency Action Level scheme).	
RE-A9 Release Energy	ESTIMATE the energy of release for each release category based on generic analysis.	ESTIMATE the energy of release for each plume of each release category based on a facility-specific analysis (e.g., from the Level 1/2 source term analysis).	
RE-A10 Release Height / Location	ESTIMATE the release height for each release category based on generic analysis.	ESTIMATE the release height for each plume of each release category based on a facility-specific analysis that considers the physical release location.	ESTIMATE the release height and release location (e.g., building, stack, etc.) for each plume of each release category based on a facility-specific analysis that considers the physical release location.
RE-A11 Isotopic Grouping	For multi-isotopic releases, GROUP the isotopes into bins or classes based on similar physical and chemical characteristics.		MODEL each isotope included in the inventory (see RE-A5) individually (i.e., do not group isotopes).
RE-A12 Particle Size	ESTIMATE a single particle size for each release category based on recognized sources (e.g., NUREG-1150 [11]).	ESTIMATE multiple particle sizes for each release category based on recognized sources or JUSTIFY use of an alternate approach.	ESTIMATE multiple particle sizes for each release category based on facility-specific analysis.

Table 4.5.3-1(a) Supporting Requirements (SRs) for HLR-RE-A (Cont'd)

The radionuclide release(s) shall be characterized so as to support the offsite consequence analysis.

Index No. RE-A	Capability Category I	Capability Category II	Capability Category III
RE-A13 Hazard Groups	IDENTIFY hazard groups that have the potential for affecting protective-action parameters (e.g., seismic event that impacts evacuation).		
RE-A14 Frequency	COLLECT the frequency of each release category based on generic analysis or analysis performed on a comparable plant.	COLLECT the frequency of each release category based on a facility-specific analysis.	
RE-A15 Uncertainty Review	REVIEW for insights the uncertainty information provided by the Level 1/2 analysis for each of the release characteristics of the release categories.		
RE-A16 Uncertainty Treatment	USE point estimates or mean values for the attributes of the source term used to characterize each release category.	EVALUATE multiple source terms for each release category. CHARACTERIZE uncertainty from the collection of source terms.	USE a distribution of source terms provided in the Level 1/2 analysis for each release category to evaluate the uncertainty in the release category characterization.

NOTE:

(1) For example, lists of significant isotopes for LWRs are available in the literature (e.g., WASH-1400 [12], NUREG-1150 [11], NUREG-1465 [13], NUREG/CR-7110 [14]).

Table 4.5.3-1(b) Supporting Requirements (SRs) for HLR-RE-B

Documentation of radionuclide release characterization shall be consistent with the applicable supporting requirements.

Index No. RE-B	Capability Category I	Capability Category II	Capability Category III
RE-B1 Release Documentation	DOCUMENT the radionuclide release characterization in a manner that facilitates PRA applications, upgrades, and peer review.		
RE-B2 Typical Documentation	DOCUMENT the process used for radionuclide release characterization for Level 3 analysis including the inputs, methods, and results. For example, documentation typically includes *(a)* source term release magnitude, *(b)* radionuclide inventory data, *(c)* source term release timing, *(d)* warning time for protective actions, *(e)* energy of release, *(f)* release height/location, *(g)* particle size, *(h)* hazard group, *(i)* release frequency, and *(j)* parameter estimate including the characterization of uncertainty, as appropriate.		
RE-B3 Model Uncertainty and Assumptions	DOCUMENT the sources of model uncertainty and related assumptions (as identified in Requirements QT-C1 and QT-C2) associated with radionuclide release development.		

4.6 PROTECTIVE ACTION PARAMETERS AND OTHER SITE DATA (PA)

4.6.1 Introduction

Results of interest in a Level 3 PRA typically involve dose received by individuals and costs associated with radiological impacts, such as remediation of contaminated land. Past consequence analyses have found that costs are generally highly correlated to the impacted population. Thus, the population distribution surrounding a site is significant to the results of a Level 3 analysis.

Many nuclear facilities have a lower population locally (e.g., within 10 miles) and larger population centers in the surrounding region (e.g., within 50 miles) of the facility. The distribution of the population surrounding a facility affects the potential impacts of a radiological release, especially when combined with prevailing wind directions.

Licensed commercial nuclear plants have prepared plans for the emergency evacuation of local populations (e.g., within approximately 10 miles). These plans are based on evacuation time estimate (ETE) studies that provide estimates for how quickly local persons can be evacuated should the need arise. National, state, county, and facility guidance documents and procedures also provide important inputs regarding when different protective actions should be specified (e.g., shelter in place, partial evacuation, land interdiction). These site-specific protective actions have an important impact on the potential dose and cost consequences of a release. Some hazards (e.g., hurricanes, floods) may result in unique population responses prior to a radioactive release.

Site-specific data include local and regional land characteristics and land use (e.g., fraction of land that is not water, fraction of land devoted to farming). These site-specific data are useful to more accurately model site-specific attributes that may impact the consequences.

4.6.2 Objectives

The objectives of the protective-action parameters and other site data technical element are to

(a) ensure that the protective actions are properly defined to enable calculation of the impact of mitigation strategies in the consequence analysis; and

(b) ensure that other site, local, and regional data are properly defined and developed to support the consequence analysis.

4.6.3 High Level Requirements

The HLRs for the protective-action parameters and other site data to be used in an acceptable Level 3 consequence analysis are provided in Table 4.6.3-1.

Table 4.6.3-1 High Level Requirements (HLRs) for Protective Action Parameters and Other Site Data (PA)

Designator	Requirement
HLR-PA-A	Appropriate short- and long-term protective actions shall be used in the modeling.
HLR-PA-B	Appropriate site, local and regional population, land use, and geographic data shall be used.
HLR-PA-C	Documentation of protective-action parameters and other site data shall be consistent with the applicable supporting requirements.

Table 4.6.3-1(a) Supporting Requirements (SR) for HLR-PA-A

Appropriate short-and long-term protective actions shall be used in the modeling.

Index No. PA-A	Capability Category I	Capability Category II	Capability Category III
PA-A1 Protective Actions	If protective actions are not to be modeled, JUSTIFY that modeling of protective actions is not required [see Note (1)].	INCLUDE short- and long-term protective actions in the model. For example: *(a)* evacuation *(b)* sheltering *(c)* relocation *(d)* land interdiction / remediation *(e)* food interdiction / remediation	INCLUDE short and long-term protective actions in the model. For example: *(a)* evacuation *(b)* sheltering *(c)* relocation *(d)* land interdiction/remediation *(e)* food interdiction / remediation *(f)* water interdiction / remediation INCLUDE additional site-specific protective actions that may be of interest. For example: *(a)* potassium iodide (KI) pills *(b)* alternate modes of evacuation (e.g., walking) *(c)* protective inhalation equipment]
PA-A2 Incident Phases	No requirement (see PA-A1).	BASE protective-action modeling upon criteria appropriate to the phase of the incident including consideration of the following: *(a)* early phase – the first hours or days of an event (sometimes called the emergency phase), when evacuation and sheltering decisions are made and implemented based on plant status and anticipated or in-progress releases *(b)* intermediate phase – the first weeks to months following a release, when protective actions are mainly based on environmental measurements *(c)* late/long-term phase – the subsequent months to years following a release, when recovery/remediation actions are conducted and completed, and land is released for unrestricted use or condemned	
PA-A3 Input Sources	No requirement (see PA-A1).	BASE protective-action modeling (e.g., evacuation time estimate, dose criteria for evacuation, sheltering, food and land interdiction) upon current applicable documents (e.g., emergency plan, evacuation time estimate study) and recommendation documents from recognized organizations (e.g., Environmental Protection Agency, Food and Drug Administration, state or local bodies, utility). JUSTIFY the use of these recommendations (e.g., local requirements are more stringent than national requirements, use of international standards in lieu of U.S. standards).	
PA-A4 Cohorts	No requirement (see PA-A1).	USE two cohorts in the protective-action modeling (e.g., one cohort for those not complying with protective actions and another cohort for those complying).	USE three or more cohorts in the protective-action modeling (e.g., one cohort for those not complying with protective actions, another cohort for those complying with protective actions, and a third cohort for those that may not evacuate quickly).

Table 4.6.3-1(a) Supporting Requirements (SR) for HLR-PA-A (Cont'd)

Appropriate short-and long-term protective actions shall be used in the modeling.

Index No. PA-A	Capability Category I	Capability Category II	Capability Category III
PA-A5 Protective Action Compliance	No requirement (see PA-A1).	MODEL with assumptions regarding compliance with protective actions (e.g., a uniform percentage of the population is assumed to not evacuate) based on generic data sources (e.g., NUREG-1150 [11]).	MODEL compliance with protective actions based on site-specific evaluation.
PA-A6 Shelter-in-Place	No requirement (see PA-A1).	MODEL temporary shelter-in-place for the cohort(s) that evacuates, if appropriate for the release category and conditions.	MODEL temporary shelter-in-place for the cohort(s) that evacuates, if appropriate for the release category and conditions. INCLUDE shelter-in-place for appropriate cohorts Examples of appropriate cohorts include *(a)* institutionalized individuals, such as those in hospitals, nursing homes, or prisons; *(b)* and staged evacuation groups.
PA-A7 Sheltering Parameters	No requirement (see PA-A1).	USE sheltering parameters (e.g., shielding values) from generic data sources (e.g., NUREG-1150 [11]).	USE sheltering parameters (e.g., shielding values) developed from regional data (e.g., housing types).
PA-A8 Evacuation Route	No requirement (see PA-A1).	USE simplified evacuation modeling for applicable cohort(s), such as *(a)* radial evacuation, and *(b)* evacuation of full plume exposure pathway emergency planning zone (EPZ).	USE site-specific and event-specific evacuation modeling for applicable cohort(s), such as *(a)* road network (e.g., following transportation paths), and *(b)* partial evacuation based on event specific release considerations (e.g., keyhole evacuation based on wind direction).
PA-A9 Delay Times	No requirement (see PA-A1).	ESTIMATE the delay time to the start of shelter-in-place and evacuation movement by the general public for applicable cohort(s) [see Note (2)].	ESTIMATE the delay time to the start of shelter-in-place and evacuation movement [see Note (2)] for different cohorts (e.g., individuals at schools and hospitals, employees who travel home prior to evacuation).

Table 4.6.3-1(a) Supporting Requirements (SR) for HLR-PA-A (Cont'd)

Appropriate short-and long-term protective actions shall be used in the modeling.

Index No. PA-A	Capability Category I	Capability Category II	Capability Category III
PA-A10 Evacuation Speed	No requirement (see PA-A1).	ESTIMATE the evacuation speed based on site-specific evacuation studies. Use of a constant average evacuation speed for applicable cohort(s) is acceptable. ENSURE the speed estimates, as a minimum, incorporate specific consideration of *(a)* daytime vs. nighttime impacts, *(b)* regional-specific adverse weather conditions, *(c)* special events (e.g., festivals) that significantly impact traffic conditions, and *(d)* transient populations.	ESTIMATE the evacuation speed(s) based on site-specific evacuation studies. ENSURE the speed estimates, as a minimum, incorporate specific consideration of *(a)* daytime vs. nighttime impacts, *(b)* regional-specific adverse weather conditions, *(c)* special events (e.g., festivals) that significantly impact traffic conditions, *(d)* transient populations, *(e)* partial EPZ or staged evacuation, and *(f)* shadow evacuation. INCLUDE consideration of the factors that may influence speed estimates [see Note (3)].
PA-A11 Hazard Impacts	No requirement (see PA-A1).	EVALUATE the effects of the initiating hazards (including seismic and external flood) on protective-action parameters including *(a)* evacuation speed, *(b)* delay times, and *(c)* potential for shelter in place (e.g., damaged sheltering structures).	EVALUATE the effects of the initiating hazards (including seismic and external flood) on protective-action parameters including *(a)* evacuation speed, *(b)* delay times, *(c)* potential for shelter in place, and *(d)* changes to evacuation routes.
PA-A12 Parametric Uncertainty	No requirement (see PA-A1).	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the input parameters that are judged to be significant to the results.	ESTIMATE a mean value and a statistical representation of the uncertainty interval of the input parameters.

NOTES:
(1) Some Level 3 analyses may not require the modeling of protective actions.
(2) For example, the delay time for a nuclear power plant would typically include the following:
(a) time of the general emergency declaration by the site per the site emergency procedures (e.g., emergency action level scheme) (see also RE-A8)
(b) time required for the site to notify offsite public emergency response officials

Table 4.6.3-1(a) Supporting Requirements (SR) for HLR-PA-A (Cont'd)

Appropriate short-and long-term protective actions shall be used in the modeling.

Index No. PA-A	Capability Category I	Capability Category II	Capability Category III

(c) time required for public officials to initiate notifications to the general public
(d) time required for the public to receive specific instructions (e.g., shelter-in-place, evacuate)
(e) time required to secure personal property
(f) time required to load vehicles for evacuation

These data are generally available in the site-specific ETE study.

(3) A variety of factors may influence evacuation speeds including
(a) speed variations along the evacuation route due to changing traffic conditions (e.g., bottle necks),
(b) use of special evacuation traffic measures (e.g., two-way public roads converted to one-way public roads),
(c) different speeds for individual evacuation cohorts,
(d) speed variations based on individual weather sequences to account for adverse weather, and
(e) impacts of initiating hazards (e.g., seismic) (see PA-A11).

Table 4.6.3-1(b) Supporting Requirements (SRs) for HLR-PA-B

Appropriate site, local and regional population, land use, and geographic data shall be used.

Index No. PA-B	Capability Category I	Capability Category II	Capability Category III
PA-B1 Population Estimates	ASSUME local and regional population distributions [see Note (1)]. JUSTIFY the population distribution assumptions (e.g., population distribution considered bounding for the analysis).	DEVELOP site-specific local and regional population estimates based upon recognized demographic sources (e.g., U.S. census data) [see Note (1)]. ADJUST data as needed to account for the time period of interest (e.g., projections to a specific year). INCLUDE transient populations (e.g., employees, recreational individuals) in local data.	DEVELOP site-specific local and regional population estimates based upon recognized demographic sources (e.g., U.S. census data) [see Note (1)]. ADJUST data as needed to account for the time period of interest (e.g., projections to a specific year). INCLUDE transient populations (e.g., employees, recreational individuals) in local data. ENSURE population estimates account for event specific variations, such as daytime vs. nighttime and special events (e.g., festivals). EVALUATE the potential for double-counting individuals.
PA-B2 Land Use Data	BASE land use data (e.g., area that is land vs. water, fraction of land devoted to farming, agricultural production) on generic sources or simplified assumptions (e.g., all area is habitable land).	BASE land use data (e.g., area that is land vs. water, fraction of land devoted to farming, agricultural production) on regional specific sources (e.g., county data, maps). ENSURE the data reflect intra-regional differences (e.g., differences between counties within a region).	

Table 4.6.3-1(b) Supporting Requirements (SRs) for HLR-PA-B (Cont'd)

Appropriate site, local and regional population, land use, and geographic data shall be used.

Index No. PA-B	Capability Category I	Capability Category II	Capability Category III
PA-B3 Plant Dimensions	ESTIMATE physical plant characteristics (e.g., building dimensions, stack heights) based on generic sources (e.g., typical PWR containment heights).	USE site-specific physical plant characteristics (e.g., building dimensions, stack heights).	
PA-B4 Geographic Location	IDENTIFY the release-source geographic location (e.g., reactor building, mid-way between multiple reactors, longitude/latitude).		
PA-B5 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the input parameters that are judged to be significant to the results.		ESTIMATE a mean value and a statistical representation of the uncertainty interval of the input parameters.

NOTE:

(1) “Local” refers to the geographical area associated with the plume exposure pathway EPZ (e.g., approximately 10-mile radius). Regional refers to the geographical area evaluated in the model that is beyond the local area (e.g., 10- to 50-mile radius).

Table 4.6.3-1(c) Supporting Requirements (SRs) for HLR-PA-C

Documentation of protective-action parameters and other site data shall be consistent with the applicable supporting requirements.

Index No. PA-C	Capability Category I	Capability Category II	Capability Category III
PA-C1 Protective Action Documentation	DOCUMENT the protective-action modeling and site-specific parameters in a manner that facilitates PRA applications, upgrades, and peer review.		
PA-C2 Typical Documentation	DOCUMENT the processes used to develop the protective-action parameters and the supporting engineering bases including the inputs, methods, and results. For example, this documentation typically includes *(a)* protective actions modeled (e.g., shelter-in-place, radial evacuation), *(b)* protective-action parameters and bases (e.g., evacuation speed), *(c)* incident phases modeled, *(d)* population distribution and bases, *(e)* land use data, *(f)* plant physical characteristics (e.g., dimensions, geographic location), and *(g)* references to generic sources and documents.		
PA-C3 Uncertainty and Assumptions	DOCUMENT the sources of model uncertainty and related assumptions (as identified in QT-C1 and QT-C2) associated with protective actions.		

4.7 METEOROLOGICAL DATA (ME)

4.7.1 Introduction

At the heart of a consequence analysis is a valid set of meteorological data. Therefore, a key objective to ensuring an accurate assessment is to locate sources of valid and representative meteorological data, which are input to atmospheric transport and dispersion (ATD) codes, that provide the basis for consequence analysis calculations. The meteorological data are needed for a sufficient period of time (i.e., temporally representative) to enable determination of the frequency of occurrence of local conditions that affect atmospheric transport and dispersion.

Of particular importance to consequence analyses is rainfall amount and intensity. The frequency of occurrence and intensity of rain can have a significant effect on the overall dose assessment. Rainfall results in two very important phenomena: (1) it scavenges particles and halogens out of the atmosphere that affect inhalation doses, and (2) the radioactive material that is deposited on the ground results in radiation dose from the groundshine pathway. When radioactive material is removed from the air, the dose due to the plume shine and inhalation pathways is reduced as the distance increases from the source.

Wind direction is important when population centers, sensitive receptors, and food crop and meat animal locations are considered. If there were a higher frequency of wind blowing toward a population center or farm area, then the overall impact and risk to the population at large would be higher. These circumstances would result in larger mean health effects.

Wind speed is important in determining the plume dilution, as well as the transport time, which in turn affects shelter/evacuation decision-making. In addition, wind speed affects plume rise, as higher winds tend to limit plume rise. Wind speed also affects the atmospheric stability. Faster winds create a well-mixed condition, which is a neutral stability that can occur any time of the day or night. Lighter winds are more conducive to very stable conditions at night and very unstable conditions during the day.

Atmospheric stability is used to determine the horizontal and vertical turbulence intensities in the atmosphere. More turbulence during unstable conditions promotes better dispersion and lower individual doses but covers a wider area. Generally speaking, there is more turbulence in the daytime than at night due to the ground heating by incoming solar radiation and subsequent convective eddy formation. When winds are strong, the effects of heating in the daytime and cooling at night are not as significant, as a well-mixed condition occurs.

4.7.2 Objective

The objective of the meteorological technical element is to ensure that appropriate and valid meteorological data are compiled for use as input to the atmospheric dispersion model(s).

4.7.3 High Level Requirements

The HLRs for the meteorological data to be used in an acceptable Level 3 consequence analysis are provided in Table 4.7.3-1.

Table 4.7.3-1 High Level Requirements for Meteorological Data (ME)

Designator	Requirement
HLR-ME-A	Accurate meteorological data from spatially representative location(s) shall be compiled.
HLR-ME-B	Documentation of meteorological data shall be consistent with the applicable supporting requirements.

Table 4.7.3-1(a) Supporting Requirements (SRs) for HLR-ME-A

Accurate meteorological data from spatially representative location(s) shall be compiled.

<table>
<tr><th>Index No.
ME-A</th><th>Capability Category I</th><th>Capability Category II</th><th>Capability Category III</th></tr>
<tr><td>ME-A1
Meteorological Data Collection</td><td>COMPILE meteorological data records from the region.

JUSTIFY that the data are spatially representative of the site (i.e., source) location and the region [see Notes (1) and (2)].</td><td>COMPILE meteorological data records from the site.

JUSTIFY that the data are spatially representative of the site (i.e., source) location [see Note (1)].</td><td>COMPILE meteorological data records from the site and region.

JUSTIFY that the data are spatially representative of the site (i.e., source) location and the region [see Note (1)].</td></tr>
<tr><td>ME-A2
Period of Record</td><td>COMPILE hourly meteorological data for a one-year period from a location representative of the source and its surroundings.</td><td>EVALUATE hourly meteorological data for multiple years from the site location to select a one-year period of data that is representative of current conditions.</td><td>EVALUATE meteorological data on a time scale less than one hour (e.g., 15-minute) for multiple years from the site location to select a one-year period of data that is representative of current conditions or USE multiple years of meteorological data in a single calculation.</td></tr>
<tr><td>ME-A3
Data Recovery Rate and Substitution</td><td>COMPILE meteorological data that does not have large blocks (e.g., weeks) of missing data.

JUSTIFY use of data with less than 90% data recovery (e.g., data available for each month of the year).

SUBSTITUTE data to complete the data set using interpolation techniques or techniques from regional recognized sources (e.g., government weather service stations) where onsite meteorological data are not available.</td><td colspan="2">COMPILE meteorological data including rainfall that has a combined data recovery at or above 90% for the period of record.

For missing data, USE data from a different tower elevation or co-located tower (if available), adjusted to complete the database.

SUBSTITUTE data to complete the data set using interpolation techniques, substitution techniques, or techniques from regional recognized sources (e.g., government weather service stations) where onsite meteorological data are not available.

ENSURE that the substitution process to make such determinations in accordance with ME-A8 has been reviewed by a qualified meteorologist or professional with equivalent training or experience. The review shall consider terrain, presence of nearby water bodies, and other meteorological phenomena that may affect airflow trajectories.

[See Note (3).]</td></tr>
</table>

Table 4.7.3-1(a) Supporting Requirements (SRs) for HLR-ME-A (Cont'd)

Accurate meteorological data from spatially representative location(s) shall be compiled.

Index No. ME-A	Capability Category I	Capability Category II	Capability Category III
ME-A4 Accuracy	COMPILE meteorological data and JUSTIFY applicability.	COMPILE meteorological data that has been collected under a system of calibrations, maintenance activities, and instrument exposure that meets or exceeds the requirements of the ANSI/ANS-3.11-2015 [15] standard for "Determining Meteorological Information at Nuclear Facilities" or its equivalent. Table 1 of ANSI/ANS-3.11-2015 [15] establishes accuracies for each parameter. JUSTIFY inclusion of data that is not in compliance with ANSI/ANS-3.11-2015 [15] or its equivalent (e.g., evaluate activities used to collect the available data to demonstrate the deviations are minimal).	
ME-A5 Parameters to Be Measured	EXTRACT the following sequential hourly meteorological parameter measurements: *(a)* wind speed and direction at approximately the 10-meter level *(b)* some measurement or observation that can be used to determine the atmospheric stability class (see SR ME-A7)	EXTRACT the following sequential hourly meteorological parameter measurements: *(a)* wind speed and direction at approximately the 10-meter level *(b)* Some measurement or observation that can be used to determine the atmospheric stability class (see SR ME-A7) *(c)* precipitation	EXTRACT the following sequential meteorological parameter measurements: *(a)* wind speed and direction at approximately the 10-meter level *(b)* some measurement or observation that can be used to determine the atmospheric stability class (see SR ME-A7) *(c)* precipitation *(d)* additional data required for more complex models (e.g., ambient temperature at the level of effluent discharge humidity, wind speed/direction at higher elevations)
ME-A6 Mixing Height	COMPILE seasonal regional afternoon mixing height from regional data (e.g., Holzworth 1972 [16])	COMPILE seasonal morning and afternoon mixing heights determined from regional data (e.g., Holzworth 1972 [16]).	COMPILE hourly mixing heights measured at the source location by remote monitoring [e.g., sonic detection and ranging (SODAR) or light detection and ranging (LIDAR)] techniques or estimated based on site-specific conditions.
ME-A7 Stability Classification	USE a simplified stability classification approach [see Note (4)].	USE a stability classification method from recognized sources [see Note (5)].	USE, and JUSTIFY use of, any one of a number of stability typing methods that are available [see Note (6)].

Table 4.7.3-1(a) Supporting Requirements (SRs) for HLR-ME-A (Cont'd)

Accurate meteorological data from spatially representative location(s) shall be compiled.

Index No. ME-A	Capability Category I	Capability Category II	Capability Category III
ME-A8 Quality Review	REVIEW meteorological data for its accuracy by a qualified meteorologist or a professional with experience in collection and reduction of meteorological data to determine adequacy of data recovery and its validity [see Note (7)].		REVIEW meteorological data for its accuracy by a qualified meteorologist or a professional with experience in collection and reduction of meteorological data to determine adequacy of data recovery and its validity [see Note (7)]. USE some form of data quality checking method, (e.g., METDATAQC code, NUREG-0917 [17], techniques identified in ANSI/ANS-3.11-2015 [15]).
ME-A9 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty associated with meteorological parameters that are judged to be significant to the results.	ASSESS quantitatively the impact of varied meteorological data on the metrics of interest. Sensitivity studies are an acceptable means (e.g., selecting different weather trials in the annual data set, assessing multiple years of data).	ASSESS quantitatively the impact of varied meteorological data on the metrics of interest by evaluating all potential weather trials in an annual set and multiple years of data.

NOTES:

(1) Factors to be assessed may include proximity to the site, exposure of the site to local influences (i.e., terrain-induced effects, such as river-valley orientation; nearness to large bodies of water), long-term climatology (e.g., wind direction frequencies, wind speed averages, and stability category averages (e.g., AMS 1977 [18]), and poor data recovery rate.

(2) Data from airports may be inadequate for consequence assessment. The reported wind speeds may only be accurate down to one mph. Many airport records do not have adequate procedures for reporting lower speeds or may not have anemometers that are sensitive at low wind speeds. In addition, there is often a runway direction bias in older manually recorded wind direction observations. Lastly, the technique for typing atmospheric turbulence into stability classes results in a larger frequency of slightly stable and neutral stability and a lower frequency of very unstable and very stable conditions.

(3) ANSI/ANS-3.11-2015 [15] provides information on qualified meteorologists and data substitution.

(4) An example of a simplified approach is the stability array (STAR) method (Turner 1970 [19]).

(5) Examples of recognized sources include

(a) delta-T and the table for converting to stability class (Regulatory Guide 1.23 [20]), and

(b) sigma-theta and the table for converting to stability class (ANSI/ANS 3.11-2015 [15]) using the U.S. Environmental Protection Agency (EPA) correction (EPA-454 [21]) for nighttime hours.

(6) Other typing methods include cloud cover or solar insolation combined with time of day and wind speed, sigma phi (i.e., standard deviation of vertical wind direction fluctuations), Richardson number, or Monin-Obukhov similarity. Guidance can be found in ANSI/ANS-3.11-2015 [15]).

(7) A common problem is wind speed data that indicate calm conditions (e.g., zero speed) a high percentage of the time due to inoperable instrumentation.

Table 4.7.3-1(b) Supporting Requirements (SRs) for HLR-ME-B

Documentation of meteorological data shall be consistent with the applicable supporting requirements.

Index No. ME-B	Capability Category I	Capability Category II	Capability Category III
ME-B1 Meteorological Documentation	DOCUMENT the meteorological data analysis in a manner that facilitates PRA applications, upgrades, and peer review.		
ME-B2 Typical Documentation	DOCUMENT the processes used to develop the meteorological data. For example, this documentation typically includes *(a)* source of data (including reasons for selection), *(b)* quality assessment, *(c)* levels of sensors, *(d)* exposure of tower, *(e)* calibration records, *(f)* period of record, *(g)* percent data recovery, and, *(h)* if used, extent of conformance with ANSI/ANS-3.11-2015 [15].		
ME-B3 Model Uncertainty and Assumptions	DOCUMENT sources of model uncertainty and related assumptions (as identified in QT-C1 and QT-C2) associated with developing the meteorological data.		

4.8 ATMOSPHERIC TRANSPORT AND DISPERSION (AD)

4.8.1 Introduction

Requirements in this section are related to the characterization of atmospheric transport and dispersion of released material into the atmosphere. The hourly meteorological data, required as input, are usually generated by processing data collected at the facility location or at nearby government weather service stations that have spatially representative data.

Simulation of ATD usually requires the use of ATD models. The most commonly used model used to characterize this “plume” of airborne material is referred to as the straight-line steady-state Gaussian model. This model calculates ground-level instantaneous and time-integrated airborne concentrations in the plume. The amount of particulate material deposited on the ground is commonly calculated using a constant deposition velocity. Its results are a function only of distance from the source. The more sophisticated models allow temporal changes in atmospheric stability, wind speed, and other variables for each successive hour of travel time. Some more complex codes also allow the wind speed and wind direction to change with time or develop three-dimensional wind fields to account for the influence of a non-uniform wind field affected by terrain obstacles or sea-breeze flows. For instantaneous releases, a three-dimensional Gaussian puff model is usually employed. Longer-period releases are commonly treated with Gaussian plume models or more sophisticated models, as previously discussed.

In general, consequence modeling codes simulate the fate and transport of the radioactive plume as it travels for many hours during which the meteorological conditions are very likely to change in both time and space. In principle, there will be a different sequence of hourly weather changes for each of the 8,760 hours during a full year at which the accident might take place. When there were slower computers, it was impractical to run each of these sequences in turn. Consequently, a statistical method was devised for obtaining a random sample by selecting starting times that were equally spaced throughout the year. The sample might also be obtained by first combining the weather sequences into groups in which the pattern of hourly weather changes was similar (e.g., joint frequency distributions) and then ensuring that the sampling process covered all of the groups without significant bias. The question of how best to sample weather data is important. Contemporary computing techniques are now capable of running all hours separately. In this manner, the very low probability "tails" of the distribution associated with the variation in the meteorological conditions can be determined for consideration in the analysis.

The Gaussian model can be modified to take into account a number of phenomena, although such models are limited in describing certain highly complex atmospheric phenomena (e.g., airflow trajectory reversals). Allowance is usually made for the mixing of the radioactive plume as it emerges into the turbulent wake due to the aerodynamic effects on the wind field by a nearby building. The planetary boundary layer (PBL), which is the layer of turbulent air adjacent to the surface of the earth, is almost always capped by an overhead inversion, which is a layer of very stable air that acts as an effective barrier to the upward dispersion of the plume. The height of the base of this boundary layer, often termed "the mixing height," depends on several phenomena including the intensity of turbulence in the layer of air beneath it, which in turn depends on the time of day and the wind speed. Mixing heights are generally lower at night when inversions occur.

If the release scenario involves a heated discharge, the plume is buoyant due to the temperature difference between the plume and the ambient air, and it will rise according to plume rise algorithms. The plume will also rise due to the momentum associated with the exit velocity. When there are strong winds, the vertical rise of the plume is limited, and it assumes a more horizontal path. However, during calm wind conditions, the plume rises straight up until reaching equilibrium with the atmosphere. Some codes allow the plume to penetrate the inversion lid, although most reflect the plume back to the ground.

As the plume of radioactive material travels downwind from the source location, various mechanisms remove the airborne material. In addition to radioactive decay, which is only dependent on plume travel time and is a function only of the wind speed, the radioactive material is also removed (i.e., depleted) by dry deposition due to settling and by precipitation scavenging or wet deposition. The rate of precipitation, the chemical form of the radioactive material, particle density and size distribution, the surface characteristics of the ground, and meteorological conditions all affect the deposition processes. Wet deposition is characterized by a simple exponential removal rate, which is dependent on the rate of precipitation. When the occurrence of precipitation is specified by the weather data, it is assumed to occur uniformly with time and throughout the vertical extent of the spatial interval of the plume. Plumes may also lose material if they impact on vegetation or terrain surfaces before reaching the ground.

Noble gases are assumed to be insoluble and non-reactive, and therefore are not removed by wet deposition. Since gases do not have a fall velocity but remain within the turbulent flows of the atmosphere, they are not removed by dry deposition.

4.8.2 Objective

The objective of the atmospheric transport and dispersion technical element requirements is to ensure that an appropriate dispersion methodology and meteorological data are used to determine the airborne concentration and ground deposition for input into dose models.

4.8.3 High Level Requirements

The HLRs for atmospheric transport and dispersion to be used in an acceptable Level 3 analysis are provided in Table 4.8.3-1.

Table 4.8.3-1 High Level Requirements for Atmospheric Transport and Dispersion (AD)

Designator	Requirement
HLR-AD-A	The analysis shall model the atmospheric transport and dispersion conditions at the site.
HLR-AD-B	The analysis shall include use of meteorological data to provide probabilistic results.
HLR-AD-C	The analysis shall model atmospheric transport and dispersion for accident-/site-specific input parameters.
HLR-AD-D	The analysis shall accommodate temporal and spatial changes in meteorological conditions.
HLR-AD-E	The analysis shall include calculation of deposition of radionuclide particles.
HLR-AD-F	Documentation of atmospheric transport and dispersion modeling shall be consistent with the applicable supporting requirements.

Table 4.8.3-1(a) Supporting Requirements (SRs) for HLR-AD-A

The analysis shall model the atmospheric transport and dispersion conditions at the site.

Index No. AD-A	Capability Category I	Capability Category II	Capability Category III
AD-A1 Dispersion Algorithm	USE a straight-line steady-state Gaussian transport and dispersion model.	USE a Gaussian transport and dispersion model or similar model with temporal variations in the meteorological data that accounts for off-centerline concentrations (e.g., segmented plume model).	USE a derivative of the Gaussian model (e.g., Gaussian puff model) or a more complex three-dimensional mass-consistent model, for example: *(a)* particle-in-cell *(b)* numerical grid *(c)* physical model *(d)* gradient transfer model *(e)* higher-order closure models (e.g., Slade 1968 [22], Randerson 1984 [23], or OFCM 1999 [24])
AD-A2 Time Scale	CALCULATE atmospheric transport and dispersion using a steady-state model (i.e., no time dependency).	CALCULATE atmospheric transport and dispersion with updates of wind speed, stability, and precipitation on a one-hour time scale.	CALCULATE atmospheric transport and dispersion with updates of wind speed, wind direction, turbulence, and precipitation on a time scale less than one hour (e.g., 15-minute).

Table 4.8.3-1(a) Supporting Requirements (SRs) for HLR-AD-A (Cont'd)

The analysis shall model the atmospheric transport and dispersion conditions at the site.

Index No. AD-A	Capability Category I	Capability Category II	Capability Category III
AD-A3 Calculation Grid	USE a model that calculates centerline concentration and deposition. SPECIFY the spatial dimensions.	USE a model that calculates concentration and deposition on a two-dimensional grid in reasonably fine geographical areas around the site. JUSTIFY the spatial grid dimensions (e.g., includes distance for results of interest, validity of the model at outer distance).	USE more advanced models with high-resolution grid that enable movement of the plume and evacuees as a function of time (see Appendix A for references to codes that provide such capability). JUSTIFY the spatial grid dimensions (e.g., includes distance for results of interest, validity of the model at outer distance).
AD-A4 Wind Fields	USE a model that includes uniform hourly wind field data from a single representative meteorological tower.		USE a model that accounts for more complex wind conditions (e.g., location affected by terrain, land/sea breeze flows).
AD-A5 Wind Speed Correction with Height	USE a model that includes wind measurements that are reasonably representative of plume travel speed and/or release height.		USE a model that accounts for site and regional variations in wind speed with height.
AD-A6 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the dispersion parameters that are judged to be significant to the results.		ESTIMATE a mean value of, and a statistical representation of, the uncertainty of the dispersion parameters that are judged to be significant to the results.

Table 4.8.3-1(b) Supporting Requirements (SRs) for HLR-AD-B

The analysis shall include use of meteorological data to provide probabilistic results.

Index No. AD-B	Capability Category I	Capability Category II	Capability Category III
AD-B1 Meteorological Data	USE meteorological data developed per the HLR-ME-A supporting requirements.		
AD-B2 Sampling	DETERMINE representative meteorological conditions to be used in the analysis (e.g., 5th percentile dispersion factor).	USE a sampling technique [e.g., Monte Carlo method, Latin hypercube sampling (LHS)]. JUSTIFY the sampling technique does not significantly alter the results of interest (e.g., demonstrate the mean results vary by less than 10% compared with mean values if all meteorological data are used).	USE all the meteorological data.

Table 4.8.3-1(c) Supporting Requirements (SRs) for HLR-AD-C

The analysis shall model atmospheric transport and dispersion for accident-/site-specific input parameters.

Index No. AD-C	Capability Category I	Capability Category II	Capability Category III
AD-C1 Height of Release	USE dispersion algorithms that characterize atmospheric transport and dispersion from elevated release heights, such as the tops of buildings or stacks.		
AD-C2 Plume Rise	USE plume rise algorithms that compute the increase in elevation of the plume above its release point due to momentum (i.e., exit velocity from a vent) and/or thermal buoyancy effects (i.e., heated discharges) (e.g., Briggs 1975 [25]).		
AD-C3 Building Wake Effects	USE algorithms that account for building wake effects (e.g., Slade 1968 [22], Randerson 1984 [23], Regulatory Guide 1.145 [26]).		

Table 4.8.3-1(d) Supporting Requirements (SRs) for HLR-DA-D

The analysis shall accommodate temporal and spatial changes in meteorological conditions.

Index No. AD-D	Capability Category I	Capability Category II	Capability Category III
AD-D1 Meteorological Condition Variability	USE a transport and dispersion model without spatial or temporal meteorological variability.	USE a transport and dispersion model that incorporates varying meteorology and straight-line direction for each release time period (i.e., segmented plume).	USE a transport and dispersion model that incorporates a time-dependent three-dimensional wind field.
AD-D2 Multiple Plumes	USE a transport and dispersion model with a single plume.	USE a transport and dispersion model with multiple plumes.	USE a transport and dispersion model with multiple plumes consistent with the temporal resolution of the underlying meteorological data.

Table 4.8.3-1(e) Supporting Requirements (SRs) for HLR-AD-E

The analysis shall include calculation of deposition of radionuclide particles.

Index No. AD-E	Capability Category I	Capability Category II	Capability Category III
AD-E1 Dry Deposition	MODEL a single dry-deposition velocity for radionuclide particles.		MODEL multiple dry-deposition velocities to calculate dry deposition of the ground-surface (e.g., surface roughness, foliage) radionuclide particles depending on the physical characteristics of the isotopic groups (e.g., particles and halogens in vapor phase) that are released (e.g., Horst 1977 [27], Hosker 1974 [28], and Randerson 1984 [23]). INCLUDE physical characteristics that are important for defining dry deposition velocities, for example: *(a)* physical diameter *(b)* density *(c)* shape factor *(d)* particle charge *(e)* chemical reactivity
AD-E2 Wet Deposition	MODEL without wet deposition.	MODEL wet deposition of radionuclide particles for various precipitation intensities (e.g., Slinn 1977 [29], Randerson 1984 [23]).	MODEL wet deposition of radionuclide particles that includes the effects of agglomeration, cloud physics, and atmospheric chemistry (e.g., Slinn 1977 [29], Randerson 1984 [23]).
AD-E3 Depletion	MODEL without source depletion.	MODEL removal (i.e., depletion) of the radionuclide particles from the plume as deposition occurs.	
AD-E4 Resuspension	MODEL without resuspension.	MODEL resuspension of deposited radionuclide particles (e.g., Slinn 1978 [30] or Loosemore 2002 [31]).	MODEL resuspension of deposited radionuclide particles (e.g., Slinn 1978 [30] or Loosemore 2002 [31]). INCLUDE the effects of land-use categories (e.g., forest, grass lands, industrial areas, urban areas) and population density on resuspension magnitudes.
AD-E5 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the deposition and resuspension parameters that are judged to be significant to the results.		ESTIMATE a mean value of, and a statistical representation of, the uncertainty of the deposition and resuspension parameters that are judged to be significant to the results.

Table 4.8.3-1(f) Supporting Requirements (SRs) for HLR-AD-F

Documentation of atmospheric transport and dispersion modeling shall be consistent with the applicable supporting requirements.

Index No. AD-F	Capability Category I	Capability Category II	Capability Category III
AD-F1 Documentation	DOCUMENT the ATD modeling in a manner that facilitates PRA applications, upgrades, and peer review.		
AD-F2 Typical Documentation	DOCUMENT the processes used for developing the ATD modeling. For example, this documentation typically includes *(a)* ATD model, *(b)* calculation grid, *(c)* time scale, *(d)* meteorological sampling method, and *(e)* plant/site characteristics (e.g., release height, building dimensions).		
AD-F3 Uncertainty and Assumptions	DOCUMENT sources of model uncertainty and assumptions (as identified in QT-C1 and QT-C2) associated with the ATD modeling.		

4.9 DOSIMETRY (DO)

4.9.1 Introduction

Requirements for dosimetry involve computation of radiation doses received by individual receptors and population groups. Dose estimates are made for each accident using the spatial distribution of instantaneous and time-integrated airborne concentration, and deposited amounts of radioactive material calculated by the ATD model.

The dosimetry model includes the appropriate pathways contributing dose to individual receptors and population groups over short- and long-term exposures. Exposure pathways are associated with the passing plume and ground contamination resulting from deposition of radionuclides, as well as subsequent resuspension of deposited material and ingestion of contaminated food and water.

Radiological exposures in a Level 3 analysis account for both short-term and long-term effects. The short-term considers plume passage and a limited time afterward (i.e., on the order of days). The long-term considers indirect uptake of radioactivity over an extended period of time (i.e., on the order of years).

The pathways of exposure include (1) direct external exposure to radioactive material in the plume [principally due to gamma radiation (cloudshine)], (2) exposure from inhalation of radionuclides in the cloud and resuspended material deposited on the ground, (3) exposure to radioactive material deposited on the ground (groundshine), (4) radioactive material deposited onto the body surfaces (skin deposition), (5) ingestion from deposited radionuclides that make their way into the food and water pathway, and (6) liquid pathways.

Dosimetry may include consideration of protective actions to limit dose. This consideration is often in the form of shielding or protection factors. Mitigation actions are addressed in Section 4.6 of this Standard.

4.9.1.1 Dosimetry Basis Model

Dosimetry models used in the Level 3 analysis typically comply with current models and associated parameters accepted by the international community, such as the International Commission on Radiological Protection (ICRP).

4.9.1.2 Dose Conversion Factors

The dose received from radioactive material is specific to an organ or tissue and is estimated by a dose conversion factor (DCF). The DCFs take into account the migration of the radionuclide within the body, the decay of the radionuclide, and the formation of daughter isotopes that may be radioactive.

The DCF values are typically based on exposure to an adult assuming a particle size of 1.0 μm activity median aerodynamic diameter (AMAD). These values are generally applied uniformly for all ages in the general public under all release conditions.

4.9.1.3 Consumption Pathways

Deposition from an airborne plume may contaminate water and food supplies. The uptake of radionuclides by plants and animals and their transfer into the food chain for humans is a very complex process.

Consumption of contaminated food products is not restricted to persons living near the site of a release, since the food products may be transported to another location for processing and consumed in still another location. The ingestion dose therefore is typically calculated separately from the other doses (i.e., from inhalation, etc.). It is not to be added to the doses from the other modes of intake, unless it is clear that the receptor for the ingestion dose is the same as the receptor for the other modes of intake. This is important if only a portion of the total dose is to be used for this purpose [e.g., dose to the population within 80 km (50 miles) of the site for cost/benefit analyses]. If the analysis uses total dose and a linear non-threshold (LNT) dose response model, then the food pathway can be added to the other pathways without biasing the result. Once the amount of radioactive material ingested has been determined, the dose can be calculated by multiplying this amount by the DCF for ingestion.

When radioactive material is deposited on the ground through dry and/or wet deposition, some fraction of this material may eventually be transported into the potable water consumed by humans. This can be can be through (1) direct deposition to surface bodies of water and uptake through the drinking water supply, or (2) deposition to land surfaces with subsequent transfer to potable water supplies through wash-off.

4.9.1.4 Cloudshine and Groundshine

Cloudshine doses are primarily from gamma and beta radiation emitted from a plume during its passage. Simple cloudshine models are better termed as immersion models and do not account for any spatial variation in concentration. True cloudshine models account for the dimensions of the plume and the relative location of the receptor. In addition, buildings and other structures may offer protection from cloudshine in terms of shielding.

The treatment of groundshine is similar to that of cloudshine. The amount of gamma radiation received by a receptor depends on the concentration of a specific isotope on the ground. Most groundshine models assume that the receptor is standing on a planar surface with a uniform radionuclide concentration. Groundshine can continue over an extended period, so the exposure period chosen by the analyst can be an important consideration.

4.9.1.5 Skin Deposition

Doses from skin deposition are relatively small and of short duration (i.e., a few hours). The primary radionuclides of importance for skin contamination are the beta emitters. Beta particles can penetrate the surface layer of dead skin cells and damage the cells directly beneath. The dose is integrated over the time duration that the material is on the skin prior to decontamination to give the skin DCF.

4.9.2 Objective

The objective for the dosimetry technical element is to ensure that appropriate dose conversion factors are used along with the computed isotopic concentrations and depositions to determine the doses received by the tissues and organs of interest due to exposure to radioactive material via each of the relevant dose pathways.

4.9.3 High Level Requirements for Dosimetry

The HLR for dosimetry to be used in an acceptable Level 3 consequence analysis are provided in Table 4.9.3-1.

Table 4.9.3-1 High Level Requirements for Dosimetry (DO)

Designator	Requirement
HLR-DO-A	The analysis shall include applicable exposure pathways including cloudshine, groundshine, skin deposition, inhalation and ingestion, and the effect of mitigation actions on received dose.
HLR-DO-B	The analysis shall apply DCFs from recognized sources.
HLR-DO-C	Documentation of dosimetry modeling shall be consistent with the applicable supporting requirements.

Table 4.9.3-1(a) Supporting Requirements (SRs) for HLR-DO-A

The analysis shall include applicable exposure pathways including cloudshine, groundshine, skin deposition, inhalation and ingestion, and the effect of mitigation actions on received dose.

Index No. DO-A	Capability Category I	Capability Category II	Capability Category III
DO-A1 Identify Exposure Pathways	IDENTIFY the exposure pathways used in the analysis. JUSTIFY excluding any of the following pathways (e.g., demonstrate dose from excluded pathway is small in comparison to other pathways): *(a)* cloudshine *(b)* groundshine *(c)* skin deposition *(d)* inhalation *(e)* ingestion		
DO-A2 Exposure	USE the plume concentrations and deposition resulting from the ATD model to calculate doses over the exposure period(s) (see DO-A3).		
DO-A3 Exposure Period	JUSTIFY the exposure period(s) used in the analysis (e.g., exposure periods are consistent with objectives of the analysis).		
DO-A4 Cloudshine	USE a semi-infinite cloud immersion model to determine dose.	USE a semi-infinite plume model with correction factor to account for the dimensions of the plume in determining the dose.	USE a finite plume model to account for the dimensions of the plume and attenuation factors arising from build-up, and scatter in air.
DO-A5 Groundshine	USE a model that integrates groundshine over the exposure time period(s) (e.g., accounting for deposited materials both during and after plume passage).		
DO-A6 Skin Deposition	MODEL without the skin deposition pathway.	MODEL skin deposition and beta exposure to the skin from the plume.	MODEL skin deposition and beta and gamma exposure to the skin from the plume.
DO-A7 Inhalation	USE a generic breathing rate for the population.	USE and JUSTIFY breathing rates for each specified cohort (e.g., breathing rates for the anticipated activities of the cohort.)	USE and JUSTIFY breathing rates for each specified cohort (e.g., breathing rates for the anticipated activities of the cohort) including age- and gender-specific breathing rates.
DO-A8 Ingestion	MODEL without the ingestion pathway.	USE generic intake quantities of foodstuffs and water.	USE site-, age-, and seasonal-specific quantities of foodstuffs and water.
DO-A9 Dose	CALCULATE effective dose [e.g., total effective dose equivalent (TEDE)] and thyroid dose.	CALCULATE acute and committed doses from modeled pathways (see DO-A1) for effective dose and specific organ doses for which health effects are to be estimated (see HE-A2 and HE-A3).	

Table 4.9.3-1(b) Supporting Requirements (SRs) for HLR-DO-B

The analysis shall apply dose conversion factors (DCFs) from recognized sources.

Index No. DO-B	Capability Category I	Capability Category II	Capability Category III
DO-B1 Dose Conversion Factors	USE effective DCFs from recognized sources [see Note (1)].	USE organ-specific DCFs from recognized sources [see Note (1)].	USE age and gender organ-specific DCFs from recognized sources (see Note (1)].
DO-B2 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the DCF parameters that are judged to be significant to the results.		

NOTE:

(1) Examples of recognized sources for DCFs include
  (a) ICRP (e.g., ICRP 60 [32], ICRP 72 [33]), and
  (b) Federal guidance reports (FGRs) (e.g., FGR-11 [34], FGR-12 [35], FGR-13 [36]).

Table 4.9.3-1(c) Supporting Requirements (SRs) for HLR-DO-C

Documentation of dosimetry modeling shall be consistent with the applicable supporting requirements.

Index No. DO-C	Capability Category I	Capability Category II	Capability Category III
DO-C1 Dosimetry Documentation	DOCUMENT dosimetry modeling in a manner that facilitates PRA applications, upgrades, and peer review.		
DO-C2 Typical Documentation	DOCUMENT the processes used for developing dosimetry modeling. For example, this documentation typically includes *(a)* exposure pathways models, *(b)* recognized sources used for DCFs, and *(c)* protection factors.		
DO-C3 Uncertainty and Assumptions	DOCUMENT sources of model uncertainty and assumptions (identified in QT-C1 and QT-C2) associated with dosimetry modeling.		

4.10 HEALTH EFFECTS (HE)

4.10.1 Introduction

Risk models for health effects from exposure to ionizing radiation are usually divided into two categories depending on the dose received and the dose rate:

(1) *Non-stochastic or deterministic health effects, also called early or prompt effects, caused by doses exceeding certain thresholds* These health effects include both mortality and morbidity (i.e., fatalities and injuries) as outcomes and typically occur within the first few days or weeks following the exposure.

(2) *Stochastic or latent health effects* The latent health effects also include mortality and morbidity as outcomes that may occur several years after exposure. Latent health effects are usually modeled with a linear non-threshold dose-response relationship, although some codes contain other (e.g., linear-quadratic) response functions and may also include provisions to include a user-defined threshold for cancer induction.

The health effects caused by radiation exposure are subject to considerable uncertainty, which can be subdivided into parameter uncertainty and model uncertainty. Parameter uncertainty arises partly from the random or stochastic nature of the process of cell damage caused by radiation and partly from the inherent error involved in drawing inferences of effects based on small samples. Parameter uncertainty is typically characterized by establishing a probability distribution on the parameter values. This distribution expresses an analyst's degree of belief in the values the parameters could take, based on the data available. Model uncertainty is more difficult to estimate since it arises from physical limitations, such as the need to rely on analogies from animal toxicology data in estimating (e.g., the risk of pulmonary syndrome mortality). Also, estimates of radiation induced cancers rely in large measure on extrapolation of Japanese A-bomb survivor data from the high dose, high dose rates received by survivors to estimate the effects of low doses and low dose rates.

Early fatality and early injury health effects are generally modeled using a cumulative hazard function with a threshold and a number of sigmoidal functions, such as the Weibull, probit, and logistic functions. One approach in some codes is based on the Weibull hazard function. If the dose is less than the threshold dose for that particular organ and health effect, then the risk for that is set to zero. Incorporation of dose-rate effects that account for the reduction in health effects of dose protraction are accomplished by suitably adjusting the value of the dose used in the hazard function over the various time intervals of interest.

Early health effects from radiation exposure that are generally considered to lead to mortality include the following syndromes and target organs:

- *(a)* hematopoietic syndrome – the killing of blood cell precursors in the marrow after irradiation with the target organ being the red bone marrow
- *(b)* pulmonary syndrome – damage to the lungs as the target organ
- *(c)* gastrointestinal syndrome – damage to the small intestine and the colon as the target organs

Early health effects that are considered to lead to morbidity (injury) include the following:

- *(a)* prodromal syndrome – gastrointestinal and neurovascular symptoms
- *(b)* radiation pneumonitis – lung impairment
- *(c)* hypothyroidism – thyroid organ impairment
- *(d)* skin burn – skin erythema caused by radiation injury to the basal cells below the skin surface

Other early health effects from radiation exposure include impacts on the reproductive system, including the ovaries and testes, and effects on the embryo and fetus from irradiation that may include fetal death and mental retardation.

Latent health effects, mainly cancers, are most often modeled via a linear or linear-quadratic relationship between dose and response. There is considerable scientific debate regarding the presence or absence of a threshold in the dose-response relationship used to model cancer incidence following irradiation. The latest position of the national and international bodies concerned with radiation protection, as expressed in BEIR VII [37] and ICRP 103 [38], affirm the no-threshold hypothesis. Some computer codes do include provisions for a user-defined threshold that could be employed for certain purposes as an alternative method to calculate latent cancer fatalities. The risk coefficient relating risk of health effect to dose in the linear model can be modified to reflect the effects of higher dose and of lower dose rate.

Latent health effects from radiation exposure include both mortality and morbidity as outcomes. Leukemia and bone cancer are generally modeled as fatalities. Most of the remaining latent health effects, cancers of the lung, breast, gastrointestinal tract, thyroid, and bladder can be modeled with different risk coefficients for either mortality or morbidity as outcomes. Skin cancer is usually modeled only as leading to morbidity. Latent health effects may also include childhood cancers from exposures in utero and genetic effects that could lead to an increase in birth defects among the children of the exposed population.

Health effects discussed in this Standard have been limited to human populations.

4.10.2 Objective

The objective of this technical element is to ensure that the estimation of health effects of interest based on the doses computed for the consequence analysis use appropriate risk factors from known authorities.

4.10.3 High Level Requirements for Health Effects

The HLRs for health effects for an acceptable Level 3 consequence analysis are provided in Table 4.10.3-1.

Table 4.10.3-1 High Level Requirements for Health Effects (HE)

Designator	Requirement
HLR-HE-A	Each health effect input parameter that is chosen shall be clearly defined in terms of the models of the risk of health effects as a function of dose and dose rate.
HLR-HE-B	The risk models of health effects vs. dose and dose rate shall be based on recommendations of the international or national bodies or national regulatory agencies.
HLR-HE-C	Documentation of the health effect modeling shall be consistent with the applicable supporting requirements.

Table 4.10.3-1(a) Supporting Requirements (SRs) for HLR-HE-A

Each health effect input parameter that is chosen shall be clearly defined in terms of the models of the risk of health effects as a function of dose and dose rate.

Index No. HE-A	Capability Category I	Capability Category II	Capability Category III
HE-A1 Health Effects	IDENTIFY early and latent health effects. Examples of early health effects include *(a)* hematopoietic syndrome (organ: bone marrow), *(b)* pulmonary syndrome (organ: lung), *(c)* gastrointestinal syndrome (organ: small intestine/colon), *(d)* prodromal syndrome (organ: abdomen), *(e)* thyroiditis/hypothyroidism (organ: thyroid), *(f)* erythema (organ: skin), *(g)* cataract (organ: lens of eye), and *(h)* fetal death/microencephaly (organ: embryo). Examples of somatic latent health effects include *(a)* leukemia (organ: red bone marrow), *(b)* bone cancer (organ: bone surface), *(c)* breast cancer (organ: breast), *(d)* lung cancer (organ: lung), *(e)* thyroid cancer (organ: thyroid), *(f)* gastrointestinal cancer (organ: lower large intestine), *(g)* skin cancer (organ: skin), and *(h)* remainder (i.e., cancers not specifically included above).		

Table 4.10.3-1(a) Supporting Requirements (SRs) for HLR-HE-A (Cont'd)

Each health effect input parameter that is chosen shall be clearly defined in terms of the models of the risk of health effects as a function of dose and dose rate.

Index No. HE-A	Capability Category I	Capability Category II	Capability Category III
HE-A2 Early Health Effects	INCLUDE early health effect input parameters based on a simplified set of organs and/or a reduced set of radionuclides (e.g., I-131 equivalent).	INCLUDE the early health effect input parameters (e.g., dose-response parameters for a hazard function) required for the target organ of the body involved.	
HE-A3 Latent Health Effects	INCLUDE latent health effect input parameters based on a simplified set of organs (e.g., TEDE) and/or a reduced set of radionuclides (e.g., I-131 equivalent).	INCLUDE the latent health effect input parameters (e.g., dose and dose-rate effectiveness factors, cancer-incidence risk factors, and cancer-fatality risk factors) required for the target organ of the body involved.	
HE-A4 Age and Gender	USE homogenous health effect input parameters related to age and gender attributes.		ESTIMATE age- and gender-specific health effect input parameters based on organ doses.
HE-A5 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the health effect parameters that are judged to be significant to the results.		ESTIMATE a mean value of, and a statistical representation of, the uncertainty of the health effect parameters that are judged to be significant to the results.

Table 4.10.3-1(b) Supporting Requirements (SRs) for HLR-HE-B

The risk models of health effects vs. dose and dose rate shall be based on recommendations of the international or national bodies or national regulatory agencies.

Index No. HE-B	Capability Category I	Capability Category II	Capability Category III
HE-B1 Input Parameters	USE risk factors recommended by internationally recognized agencies to model the health effect input parameters including for example *(a)* BEIR V [39] or BEIR VII [37]; *(b)* ICRP 60 [32] or ICRP 103 [38]; *(c)* FGR-13 [36]; and *(d)* UNSCEAR [40]		
HE-B2 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the risk-factor parameters that are judged to be significant to the results.		ESTIMATE a mean value of, and a statistical representation of, the uncertainty of the risk factor parameters that are judged to be significant to the results.

Table 4.10.3-1(c) Supporting Requirements (SRs) for HLR-HE-C

Documentation of the health effect modeling shall be consistent with the applicable supporting requirements.

Index No. HE-C	Capability Category I	Capability Category II	Capability Category III
HE-C1 Health Effects Documentation	DOCUMENT the health effect modeling in a manner that facilitates Level 3 applications, upgrades, and peer review.		
HE-C2 Typical Documentation	DOCUMENT the processes used to develop health effect modeling. For example, this documentation typically includes *(a)* descriptions of target organs selected for early/latent fatality/injury models, and *(b)* sources used for health risk models (e.g., BEIR VII [37], ICRP 103 [38]).		
HE-C3 Uncertainty and Assumptions	DOCUMENT sources of model uncertainty and assumptions (identified in QT-C1 and QT-C2) associated with the health effect modeling.		

4.11 ECONOMIC FACTORS (EC)

4.11.1 Introduction

The economic factors that enter into an offsite consequence analysis following a radiological release are those related to the economic impacts of the release on the surrounding land and the population. These factors include the costs of various actions (e.g., evacuation, relocation, decontamination) taken to protect the public from short-term and long-term exposure via different exposure pathways, the costs of health effects and health care following exposure, and secondary economic effects.

Short-term evacuation costs include costs related to transport, food, housing, and, possibly, lost income for the time period that the affected population remains evacuated. It is evaluated in dollars per person per day. These costs can vary considerably by state and region. Similarly, short-term or temporary relocation costs may be incurred as a protective measure for people who may not have been evacuated initially in the emergency phase or may have had to extend their initial evacuation period. These costs depend on the period of time the affected population remains relocated and are similar to those for evacuation and are measured in the same units.

To protect against possible ingestion doses, agricultural products (e.g., crops, dairy products, etc.) that may have been contaminated by fallout from the release may need to be disposed of. The cost of crop disposal is estimated from the fraction of the region that is farmland, the extent of area affected where doses from ingestion would exceed acceptable limits, the average annual farm production per unit area, and whether the accident occurs during the growing season or not. Accidents that occur outside the growing season may not incur any crop disposal costs. Milk and dairy disposal costs consider the fraction of farm sales that are specifically dairy products and also the time for radioactive levels in milk to reach levels acceptable for ingestion. Many of these costs may be very site specific and depend on the value of farm production in the area, the cost of land and farm improvements, etc.

Long-term protective actions include relocation (i.e., temporary or permanent) of people and businesses from contaminated areas that have been rendered uninhabitable, decontamination, and interdiction of contaminated land (including farm land) and property (temporary or permanent). Each of these actions involves costs to society (e.g., loss of business income and agricultural production). Relocation costs for people and businesses that may have to remain relocated for fairly long periods of time, such as a few years in a region rendered uninhabitable, are expressed in dollars per person. These costs measure both personal and business losses for a period of transition and may include moving expenses. Decontamination costs depend on the actions taken during the long-term to reduce doses to acceptable levels. Several levels of decontamination may be defined in terms of increasing effectiveness and cost, where effectiveness is measured by reduction of projected dose. Decontamination costs, including the costs of waste disposal, can be defined separately for farmland and non-farmland areas and evaluated in dollars per unit area for farmland and dollars per person for non-farmland areas. If the maximum level of decontamination is not able to reduce projected doses to an acceptable level within a user-defined period, then the land or property may be permanently condemned.

Several approaches may be employed to determine the economic impact of long-term interdiction or permanent condemnation of land areas. Interdictions imply a disturbance, such as loss of productivity and more generally loss of income and wealth, in the local and regional economy. These approaches include estimation of the rate of output of land and all other productive assets in the area and integration of this value over the interdiction period. A second approach uses the concept of wealth of a particular region to estimate the total present value of land and other assets in the affected area. A third approach uses economic input-output modeling techniques applied at a regional level to estimate economic losses over a period. Many of these costs, such as regional or state wealth or productivity, are also site specific.

The costs of health effects are typically estimated by two approaches: (1) national-output maximization, and (2) social-welfare maximization. In the former approach, the cost of the health effect is estimated by the discounted present value of the loss of the person's future earnings (or output) due to the incident. Allowances are made for non-marketed output (e.g. services of healthcare providers) and other costs, such as medical expenses, as well as ad hoc factors to deal with "pain and suffering." In the latter approach, individual willingness to pay for safety is estimated and then aggregated over all affected individuals.

Secondary impacts of accident costs include several factors, such as loss of income from tourism, an increase in the cost of electricity that produces ripple effects in a wider region, and population redistribution from permanent relocation, which affects employment, incomes, and productivity. These secondary impacts are likely to be site specific.

Some costs that are not typically directly included in Level 3 consequence codes may be appropriate for some analyses (e.g., SAMA analysis). Examples of such costs include

(a) onsite cleanup costs,
(b) replacement power costs, and
(c) monetization of exposure (onsite and offsite).

4.11.2 Objective

The objective of this technical element is to ensure that the economic factors determined for the analysis use appropriate models and site-specific and regional data.

4.11.3 High Level Requirements for Economic Factors

The HLR for economic factors for an acceptable Level 3 consequence analysis are provided in Table 4.11.3-1.

Table 4.11.3-1 High Level Requirements for Economic Factors (EC)

Designator	Requirement
HLR-EC-A	Each economic parameter shall be clearly defined in terms of the model.
HLR-EC-B	Parameter estimates shall be based on relevant generic data or site specific and regional data consistent with the parameter definitions of HLR-EC-A.
HLR-EC-C	Documentation of the economic modeling shall be consistent with the applicable supporting requirements.

Table 4.11.3-1(a) Supporting Requirements (SRs) for HLR-EC-A

Each economic parameter shall be clearly defined in terms of the model.

Index No. EC-A	**Capability Category I**	**Capability Category II**	**Capability Category III**
EC-A1 Cost Categories	If economic attributes are not to be modeled, JUSTIFY that economic modeling is not required [see Note (1)].	IDENTIFY the cost categories for which parameter estimates are required. Examples of cost categories include *(a)* evacuation costs, *(b)* relocation costs including temporary unemployment, *(c)* land value, *(d)* depreciation, *(e)* crop losses, *(f)* decontamination costs, *(g)* loss of use of offsite property, and *(h)* medical costs (e.g., costs estimated based on population dose). (See Note 2.)	IDENTIFY cost categories for which parameter estimates are required using an advanced economic cost analysis approach [e.g., gross domestic product (GDP) losses using an input/output model] [see Note (2)].
EC-A2 Cost Parameters	No requirement (see EC-A1).	IDENTIFY economic model parameters for the identified cost categories of EC-A1.	

NOTES:

(1) Some Level 3 analyses may not require the calculation of economic consequences.

(2) Some Level 3 analyses may require the calculation of other economic impacts. For example, economic impacts associated with onsite losses (e.g., costs for replacement power) are not addressed in this Standard but may need to be considered.

Table 4.11.3-1(b) Supporting Requirements (SRs) for HLR-EC-B

Parameter estimates shall be based on relevant generic data or site specific and regional data consistent with the parameter definitions of HLR-EC-A.

Index No. EC-B	Capability Category I	Capability Category II	Capability Category III
EC-B1 Parameter Consistency	No requirement (see EC-A1).	ENSURE that the economic modeling parameter estimates are consistent with the parameter definitions established in EC-A1 and EC-A2.	
EC-B2 Cost Parameter Values	No requirement (see EC-A1).	ESTIMATE cost parameter values using regional data applicable to the site and generic data (as needed). USE recognized sources (e.g., U.S. Department of Agriculture, U.S. Census Bureau, U.S. Department of Labor, U.S. Department of Commerce, NUREG-1150 [11]). JUSTIFY use of generic data. ENSURE cost parameter values reflect the time frame of interest (e.g., consumer price index adjustment to account for inflation).	ESTIMATE costs using regional data applicable to the site for cost parameter values from recognized sources (e.g., Department of Agriculture, Census Bureau, Department of Labor, Department of Commerce). ENSURE cost parameter values reflect the time frame of interest (e.g., consumer price index adjustment to account for inflation).
EC-B3 Parametric Uncertainty	No requirement (see EC-A1).	CHARACTERIZE (i.e., qualitatively describe) the uncertainty of the input parameters that are judged to be significant to the results.	ESTIMATE a mean value and a statistical representation of the uncertainty interval of the cost input parameters.

Table 4.11.3-1(c) Supporting Requirements (SRs) for HLR-EC-C

Documentation of the economic modeling shall be consistent with the applicable supporting requirements.

Index No. EC-C	Capability Category I	Capability Category II	Capability Category III
EC-C1 Economic Documentation	DOCUMENT the economic analysis in a manner that facilitates Level 3 applications, upgrades, and peer review.		
EC-C2 Typical Documentation	DOCUMENT the processes used to develop the economic parameters and the supporting engineering bases including the inputs, methods, and results. For example, this documentation typically includes *(a)* parameter definitions, *(b)* generic sources used, *(c)* site-specific sources used, *(d)* time period of sources (e.g., most recent census), *(e)* adjustments to parameter estimates [e.g., consumer price index (CPI) adjustment], and *(f)* characterization of uncertainty.		
EC-C3 Uncertainty and Assumptions	DOCUMENT sources of model uncertainty and related assumptions (as identified in QT-C1 and QT-C2) associated with economic parameters.		

4.12 CONDITIONAL CONSEQUENCE QUANTIFICATION AND REPORTING (QT)

4.12.1 Introduction

Requirements associated with conditional consequence quantification ensure that the Level 3 model executes properly, provides appropriate results, and is documented in a manner that facilitates risk assessments, PRA applications, upgrades, and peer review(s).

Consequence quantification is performed using the information collected and developed in technical elements RE, PA, ME, AD, DO, HE, and EC and generally input into probabilistic consequence analysis codes. The outputs of these codes provide the conditional consequence results for the defined releases. These conditional results can be subsequently combined with the release category frequencies to develop appropriate risk metrics.

While many different codes have been developed and used worldwide in the last 30 years, relatively few Level 3 codes are currently supported. Appendix A provides a brief overview of known computer codes. These codes model the consequences associated with a postulated release, such that the code results produced are conditional. Assessment of risk requires combining Level 3 conditional results with Level 1/2 results (e.g., release frequencies). This is addressed in Section 5 of this Standard.

Each Level 3 analysis code includes algorithms that have calculation limitations. The Level 3 PRA analyst ensures that modeling is appropriately performed within the range of applicability of the code. Such applicability is not only influenced by calculation limitations, but also by the outputs of interest. For example, mean regional results (e.g., 50-mile radius population dose) are generally less sensitive to terrain impacts than results for a particular location. Therefore, use of a Level 3 PRA code for a site surrounded by variable terrain may be acceptable for a regional analysis but may not be acceptable for emergency response decision-making near the site.

Level 3 PRA results are reviewed to confirm proper code execution and that the results are reasonable. Significant contributors to results of interest are identified and uncertainties assessed. The quantification process and results are documented in a manner that facilitates applications, upgrades, and peer review. Results of interest may include mean values for consequences of interest (e.g., 50-mile population dose, 50-mile economic cost, early fatalities), upper-bound values based on weather variability (e.g., 95 percentile), and complementary cumulative distribution function (CCDF) results for particular metrics to demonstrate the pairing of consequence and probability based on weather variability.

4.12.2 Objective

The objective of the quantification technical element is to ensure that the consequence metrics are properly quantified and reviewed.

4.12.3 High Level Requirements

The HLRs for conditional consequence quantification and reporting for an acceptable Level 3 consequence analysis are provided in Table 4.12.3-1.

Table 4.12.3-1 High Level Requirements for Conditional Consequence Quantification and Reporting (QT)

Designator	Requirement
HLR-QT-A	Quantification shall use appropriate models and codes and shall account for method-specific limitations and features.
HLR-QT-B	Quantification results shall be reviewed and significant contributors to results shall be identified. The results shall be traceable to the inputs and assumptions.
HLR-QT-C	Uncertainties in the results shall be characterized, and the potential impact on the results reported.
HLR-QT-D	Documentation of the consequence quantification results (output) shall be consistent with the applicable supporting requirements.

Table 4.12.3-1(a) Supporting Requirements (SRs) for HLR-QT-A

Quantification shall use appropriate models and codes and shall account for method specific limitations and features.

Index No. QT-A	Capability Category I	Capability Category II	Capability Category III
QT-A1 Quantification	PERFORM quantification using models and computer codes that have been demonstrated to generate appropriate results when compared to accepted algorithms (e.g., Gaussian plume model).		
QT-A2 Hazards	CHARACTERIZE (i.e., qualitatively describe) the effects of the initiating hazards, including seismic and external flood, on the results of interest.	EVALUATE (e.g., sensitivity analysis) the effects of initiating hazards, including seismic and external flood, on the results of interest.	INCLUDE the effects of initiating hazards, including seismic and external flood, in the quantification of the results.
QT-A3 Limitations	IDENTIFY and CHARACTERIZE features and limitations of models and codes that could impact the results. Examples include *(a)* temporal regime – minimum/maximum plume durations; *(b)* spatial regime – minimum/maximum distances, flat earth vs. terrain impacts; and *(c)* parameter limits. JUSTIFY method specific features and limitations, as needed, that could impact results.		

Table 4.12.3-1(b) Supporting Requirements (SRs) for HLR-QT-B

Quantification results shall be reviewed and significant contributors to results shall be identified. The results shall be traceable to the inputs and assumptions.

Index No. QT-B	Capability Category I	Capability Category II	Capability Category III
QT-B1 Output Review	REVIEW output files for indications of improper quantification (e.g., error statements, warning statements, and unexpected results, such as zero values). JUSTIFY acceptance of any indications of code execution errors (e.g., document evaluation of error messages and why results are not materially impacted).		
QT-B2 Results Comparison	REVIEW code results to confirm appropriate modeling and code execution. For example, results review may include *(a)* comparing results from multiple model runs for consistency and expected trends (e.g., multiple source terms), and *(b)* comparing results with results of other studies (e.g., NUREG-1150 [11] plants) for reasonableness.		
QT-B3 Significant Contributors	IDENTIFY significant contributors to results of interest. Examples that may be investigated include *(a)* weather variability, *(b)* emergency response actions, *(c)* exposure pathways, *(d)* early phase vs. long-term phase contributors, *(e)* population cohorts (e.g., transients), and *(f)* economic inputs (e.g., population relocation costs vs. land remediation costs).		

Table 4.12.3-1(c) Supporting Requirements (SRs) for HLR-QT-C

Uncertainties in the results shall be characterized, and the potential impact on the results reported.

Index No. QT-C	Capability Category I	Capability Category II	Capability Category III
QT-C1 Model Uncertainty	IDENTIFY sources of model uncertainty.		
QT-C2 Assumptions	IDENTIFY assumptions made in the development of the consequence model.		
QT-C3 Model Impacts	For each source of model uncertainty and related assumptions identified in QT-C1 and QT-C2, respectively, IDENTIFY how the consequence model is affected (e.g., change to parameter values, change in model options, ATD model used) and limitations of the model.		
QT-C4 Parametric Uncertainty	CHARACTERIZE (i.e., qualitatively describe) the uncertainty associated with the metrics of interest.	ASSESS quantitatively the impact of meteorological variability on the metrics of interest. CHARACTERIZE (i.e., qualitatively describe) the uncertainty with the metrics of interest associated with other significant input parameters. Sensitivity studies are an acceptable basis.	PROPAGATE parameter uncertainties explicitly characterized by a probability distribution using standard sampling methods (e.g., LHS, Monte Carlo method).

Table 4.12.3-1(d) Supporting Requirements (SRs) for HLR-QT-D

Documentation of the conditional consequence quantification results (output) shall be consistent with the applicable supporting requirements.

Index No. QT-D	Capability Category I	Capability Category II	Capability Category III
QT-D1 Quantification Documentation	DOCUMENT the consequence quantification in a manner that facilitates PRA applications, upgrades, and peer review. Typical forms of results include *(a)* conditional CCDFs; *(b)* means, medians; *(c)* uncertainty (as percentile); and *(d)* range (error factor).		
QT-D2 Typical Documentation	DOCUMENT the model quantification process in a manner that facilitates the Level 3 analysis, upgrades, and peer review. For example, this documentation typically includes *(a)* computer codes used and limits of applicability, *(b)* general description of quantification process, *(c)* assumptions, *(d)* base case results (e.g., early health effects, latent health effects, economic impacts), *(e)* results of sensitivity cases, *(f)* evaluation of results including significant contributors, and *(g)* uncertainty discussion.		
QT-D3 Uncertainty and Assumptions	DOCUMENT the characterization of the sources of model uncertainty and related assumptions (as identified in QT-C3).		
QT-D4 Limitations	DOCUMENT limitations in the quantification process that would impact applications.		

Section 5
Risk Estimation (RI)

5.1 INTRODUCTION

The risk estimation technical element (RI) provides for combining the Level 3 PRA results (i.e., consequences) from technical element QT with the Level 1/2 PRA results (i.e., frequency or probability) from technical element RE to obtain a characterization of risk for specific metrics and the associated uncertainties. Therefore, risk estimation requires participation by Level 1 analysis (L1), Level 2 analysis (L2), and Level 3 analysis (L3) PRA analysts to support the estimation of the risk and especially for the identification of risk contributors to confirm the reasonableness of the analyses. Furthermore, the conduct of the L1, L2, and L3 analyses should have this risk estimation task in view.

Contributors may originate from all three levels of the PRA, as exemplified below:

- Level 1 – Initiating events, accident sequences, equipment failures, common cause failures, and operator errors
- Level 2 – Phenomenological assumptions, containment fragilities, equipment failures, common cause failures, and operator errors
- Level 3 – Short- and long-term protective-action assumptions, meteorological data, land use

5.2 OBJECTIVE

The objective for this section is to ensure that the risk estimation based on the combined results of the consequence analysis and the Level 1/2 analysis is computed adequately.

5.3 HIGH LEVEL REQUIREMENTS

The HLRs for risk estimation for an acceptable Level 1/2/3 PRA are provided in Table 5.3-1.

Table 5.3-1 High Level Requirements for Risk Estimation (RI)

Designator	Requirement
HLR-RI-A	Risk shall be estimated by combining the results of the Level 1, Level 2, and Level 3 analyses.
HLR-RI-B	The risk estimation results shall be reviewed and significant contributors to the risk results shall be identified.
HLR-RI-C	Documentation of the risk estimation shall be consistent with the applicable supporting requirements.

Table 5.3-1(a) Supporting Requirements (SRs) for HLR-RI-A

Risk shall be estimated by combining the results of the Level 1, Level 2, and Level 3 analyses.

Index No. RI-A	Capability Category I	Capability Category II	Capability Category III
RI-A1 Methodology	USE risk estimation methods and codes within known limits of applicability.		
RI-A2 Risk Estimation	CALCULATE the risk results by summing the products of the frequency and conditional consequence result for each release category.	CALCULATE the risk results by summing the products of the frequency and conditional consequence result for each release category. CALCULATE the CCDFs including weather variability for risk results.	CONVOLUTE using standard sampling methods (e.g., LHS, Monte Carlo method), distributions of ranges of values and degrees of belief for frequencies, and conditional consequence results to calculate risk results including uncertainty. ENSURE that the state-of-knowledge correlation between event frequencies, event probabilities, or other parameters that are common between the L1, L2, and L3 analyses are taken into account.
RI-A3 Risk Presentation	PRESENT the risk results for the facility/plant/event [e.g., point estimates, means, CCDFs of the selected consequence metrics, uncertainty bands, and quantitative health objective (QHO) risk metrics].		

Table 5.3-1(b) Supporting Requirements (SRs) for HLR-RI-B

The risk estimation results shall be reviewed and significant contributors to the risk results shall be identified.

Index No. RI-B	Capability Category I	Capability Category II	Capability Category III
RI-B1 Results Review	REVIEW the risk results for internal consistency and reasonableness. For example, risk results review may include *(a)* comparing results of different release categories, *(b)* comparing results of sensitivity cases, and *(c)* comparing results with results of other studies (e.g., NUREG-1150 [11] plants).		
RI-B2 Significant Risk Contributors	IDENTIFY significant contributors to risk results of interest arising from L1, L2, and L3 analyses.	CHARACTERIZE significant contributors to risk results of interest arising from L1, L2, and L3 analyses. Examples that may be investigated include *(a)* release categories/sequences, *(b)* emergency response actions, *(c)* economic inputs (e.g., population relocation costs vs. land remediation costs), *(d)* weather variability, *(e)* exposure pathways, *(f)* early phase vs. long-term phase contributors, and *(g)* population cohorts (e.g., transients).	

Table 5.3-1(b) Supporting Requirements (SRs) for HLR-RI-B (Cont'd)

The risk estimation results shall be reviewed and significant contributors to the risk results shall be identified.

Index No. RI-B	Capability Category I	Capability Category II	Capability Category III
RI-B3 Uncertainty and Assumptions	IDENTIFY sources of model uncertainty and assumptions in the development of the risk estimation.		
RI-B4 Parametric Uncertainty	CHARACTERIZE the uncertainty associated with the risk results.	ESTIMATE the uncertainty associated with the risk results.	PROPAGATE, to the extent possible, the parameter uncertainties explicitly characterized by a probability distribution. ENSURE that the state-of-knowledge correlation between event frequencies, event probabilities, or other parameters that are common between the L1, L2, and L3 analyses are taken into account.

Table 5.3-1(c) Supporting Requirements (SRs) for HLR-RI-C

Documentation of the risk estimation shall be consistent with the applicable supporting requirements.

Index No. RI-C	Capability Category I	Capability Category II	Capability Category III
RI-C1 Risk Estimation Documentation	DOCUMENT the risk estimation in a manner that facilitates applications, upgrades, and peer review.		
RI-C2 Typical Documentation	DOCUMENT the risk estimation process. For example, this documentation typically includes *(a)* methods and codes, *(b)* results of interest, *(c)* significant contributors, and *(d)* discussion of uncertainty.		
RI-C3 Uncertainty and Assumptions	DOCUMENT the characterization of the sources of model uncertainty and related assumptions (as identified in RI-B3).		
RI-C4 Limitations	DOCUMENT limitations in the risk estimation process that would impact risk-informed applications.		

Section 6
Configuration Control

6.1 PURPOSE

This section provides requirements for configuration control of a Level 3 consequence analysis to be used to support risk-informed decisions. For Level 3 analyses, the configuration control is defined as control of the process, input and output, documentation, etc. Use of computer codes that represent current practice is acceptable provided they are properly documented and referenced.

The following requirements apply to maintain configuration control.

6.2 PRA CONFIGURATION CONTROL PROGRAM

A Configuration Control Program shall be in place. It shall contain the following elements:

- *(a)* a process for monitoring inputs and collecting new information
- *(b)* a process that maintains and upgrades the analysis to be consistent with the facility/site conditions
- *(c)* a process that ensures that the cumulative impact of pending changes is considered when applying the PRA
- *(d)* a process that maintains configuration control of computer codes used to support Level 3 analysis quantification
- *(e)* documentation of the Configuration Control Program
- *(f)* a description of the process used to maintain software configuration control

6.3 MONITORING INPUTS AND COLLECTING NEW INFORMATION

The Configuration Control Program shall include a process to monitor changes in the site/facility, regional population, design, operation, maintenance, and industry-wide operational history that could affect the Level 3 analysis. The Configuration Control Program shall include a process to monitor changes to the information received as input from a Level 1 or Level 2 analysis that could affect the L3 analysis.

6.4 MAINTENANCE AND UPGRADES

The Level 3 analysis shall be maintained and upgraded, such that its representation of the as-built, as-operated plant, site, and regional inputs are sufficient to support risk-informed decisions for which it is being used.

Changes in PRA inputs or the discovery of new information identified pursuant to Section 6.3 shall be evaluated to determine whether such information warrants PRA maintenance or PRA upgrade (see Section 2 for the distinction between PRA maintenance and PRA upgrade). Changes that would impact risk-informed decisions should be incorporated as soon as practical. Changes that are relevant to a specific application shall meet the SRs pertinent to that application as determined through the process described in Section 6.3.

Changes to a Level 3 analysis due to maintenance and upgrade shall meet the requirements of the SR section of each respective part of this Standard. Upgrades of a Level 3 analysis shall receive a peer review in accordance with the requirements specified in the Peer Review Section 7 of this Standard, but limited to aspects of the analysis that have been upgraded.

When changes to a Level 1/2 analysis result in changes that impact the Level 3 analysis, the Level 3 analysis shall be maintained or upgraded.

6.5 PENDING CHANGES

This Standard recognizes that immediately following a plant/facility/site change (e.g., modifications, procedure changes, plant performance (data)), or upon identification of a subject for model improvement (e.g., population updates), a PRA may not represent the conditions until the subject plant change or model improvement is incorporated into the PRA. Therefore, the PRA configuration control process shall consider the cumulative impact of pending plant changes or model improvements, or changes in the facility/site conditions, on the application being performed. The impact of these plant changes or model improvements on the results of the PRA and the decision under consideration in the application shall be evaluated in a fashion similar to the approach used in Section 3.

6.6 USE OF COMPUTER CODES

The computer codes used to support and to perform the Level 3 analyses shall be controlled to ensure consistent reproducible results. For a Level 3 analysis, the elements of such an analysis are combined into a set of modules within the code. Users of the codes should be knowledgeable in their use and familiar with all input assumptions including default values.

As updates to the codes become available, the potential impact on the analysis should be assessed.

6.7 DOCUMENTATION

Documentation of the Configuration Control Program and of the performance of the above elements shall be adequate to demonstrate that the Level 3 analysis is being maintained consistent with the facility/site conditions.

The documentation typically includes

- *(a)* a description of the process used to monitor Level 3 inputs and collect new information,
- *(b)* evidence that the aforementioned process is active,
- *(c)* descriptions of proposed changes,
- *(d)* description of changes due to upgrades or maintenance,
- *(e)* a record of the performance and results of the appropriate peer reviews,
- *(f)* a record of the process and results used to address the cumulative impact of pending changes, and
- *(g)* a description of the process used to maintain software configuration control.

Section 7
Peer Review

7.1 PURPOSE

This section provides requirements for peer review of the consequence analysis (Level 3 part of a PRA) to be used in risk-informed decisions for nuclear installations. Consequence analyses used for applications applying this Standard shall be peer reviewed. Peer reviews for this purpose shall be performed against the requirements in those sections of this Standard applicable to the portions of the Level 3 analysis that are being used to support such applications.

The peer review shall assess the Level 3 analysis to determine if the methodology and its implementation meet the requirements of this Standard. The peer review shall also assess the appropriateness of assumptions. The purpose of the peer review is to determine the strengths and weaknesses in the analysis relative to the requirements of this Standard. The peer review need not assess all aspects of the Level 3 analysis against all requirements in the SRs section of this Standard; however, enough aspects of the analysis shall be reviewed for the reviewer(s) to achieve consensus on the assessment of each applicable supporting requirement, as well as on the adequacy of methodologies and their implementation for each Level 3 PRA technical element.

The specific number and selection of reviewers and the time spent in review should be based on the scope of the review.

7.2 FREQUENCY

Only a single complete peer review (as specified in 7.1) is necessary prior to using a Level 3 analysis in risk-informed regulatory decisions. In addition, Section 6 requires peer review for upgrades of a Level 3 analysis. When peer reviews are conducted on upgrades, the latest review shall be considered the review of record. The scope of an additional peer review may be confined to upgrades to the Level 3 analysis that have occurred since the previous review.

7.3 METHODOLOGY

The review shall be performed using a written methodology that assesses the requirements of the SRs section of each respective section of this Standard. The peer review methodology shall consist of the following elements:

- *(a)* process for selection of the peer review team
- *(b)* training in the peer review process
- *(c)* an approach to be used by the peer review team for assessing if the analysis meets the supporting requirements of the HLRs section of this Standard
- *(d)* a process by which differing professional opinions are to be addressed and resolved
- *(e)* an approach for reviewing the configuration control
- *(f)* a method for documenting the results of the review

7.4 PEER REVIEWER TEAM COMPOSITION AND PERSONNEL QUALIFICATIONS

7.4.1 Collective Team

The peer review team shall consist of personnel whose collective qualifications include

(a) the ability to assess all the technical elements of the HLR Section of this Standard, as applicable, and the interfaces between those technical elements; and

(b) the collective knowledge of the facility/plant/site characteristics.

7.4.2 Individual Team Members General

The peer review team members individually shall be

(a) knowledgeable of the requirements in this Standard for their area of review, and

(b) experienced in performing the activities related to the HLRs for which the reviewer is assigned.

To avoid a technical conflict of interest, the peer review team members shall have neither performed nor directly supervised any work on the portions of the analysis being reviewed.

7.4.3 Review Team Members for Upgrades

When a peer review is being performed on an upgrade, reviewers shall have knowledge and experience appropriate for the specific HLRs being reviewed. However, the other requirements of this section shall also apply. The number of peer review members shall be commensurate with the extent of the review with a minimum of two reviewers, except as permitted in 7.4.4 for review of a single technical element.

7.4.4 Knowledge of Specific Aspects of Level 3

The peer reviewer shall also be knowledgeable (by direct experience) of the specific methodology, code, tool, or approach that was used in the technical element assigned for review. Understanding and competence in the assigned area shall be demonstrated by the range of the individual's experience in the number of different independent activities performed in the assigned area, as well as the different levels of complexity of these activities.

One member of the peer review team (i.e., the technical integrator) shall be familiar with all the technical elements identified in the section of this Standard under review and shall have demonstrated the capability to integrate these technical elements. When more than one section is under review, a separate technical integrator may be used for each section.

The peer review team shall have a team leader to lead the team in the performance of the review. The team leader need not be the technical integrator.

The peer review should be conducted by a team with a minimum of five members, performed over a time necessary to address the specific technical elements under review. Exceptions to the requirements of this paragraph may be taken based on the availability of appropriate personnel to develop a team. A single-person peer review shall only be justified when the review involves an upgrade of a single technical element and the reviewer has acceptable qualifications for the technologies involved in the upgrade. All such exceptions shall be documented in accordance with Section 7.4.8 of this Standard. Regardless of any such exceptions, the collective qualification of the review team shall be appropriate to the full scope of SRs within the scope of the Level 3 analysis being peer reviewed.

7.4.5 Review of Level 3 Technical Elements to Confirm the Methodology

The peer review team shall use the requirements of this section and the SRs associated with each technical element to determine if the methodology and the implementation of the methodology for each technical element meet the requirements of this Standard. Additional material for those technical elements may be reviewed depending on the results obtained. The judgment of the reviewer shall be used to determine the specific scope and depth of the review in each technical element.

The results of the overall Level 3 analysis, including models and assumptions, and the results of each technical element shall be reviewed to determine their reasonableness given the facility design and site characteristics. The HLRs and SRs of this Standard shall be used by the peer review team to assess the completeness of a technical element.

7.4.6 Expert Judgment

The use of expert judgment to implement requirements in this Standard shall be reviewed and evaluated as to adequacy and appropriately documented.

7.4.7 PRA Configuration Control

The peer review team shall review the process, including implementation, for maintaining or upgrading the Level 3 analysis against the configuration control requirements of this Standard.

7.4.8 Documentation

7.4.8.1 Peer Review Team Documentation

The peer review team documentation shall demonstrate that the review process appropriately implemented the review requirements.

Specifically, the peer review documentation shall include the following:

- *(a)* identification of the version of the Level 3 analysis reviewed
- *(b)* statement of the scope of the peer review
- *(c)* names of the peer review team members
- *(d)* a brief resume on each team member describing the individual’s employer, education, training, and Level 3 experience and expertise
- *(e)* technical elements reviewed by each team member
- *(f)* a discussion of the extent to which each technical element was reviewed including a list of SRs that were reviewed and justification for any SRs within the scope that were not reviewed
- *(g)* results of the review identifying any differences between the requirements in the SRs section of this Standard and the methodology implemented defined to a sufficient level of detail that will allow the resolution of the differences
- *(h)* identification and significance of exceptions and deficiencies with respect to SRs including an assessment of input assumptions that the reviewers have determined to be relevant
- *(i)* at the request of any peer reviewer, differences or dissenting views among peer reviewers
- *(j)* recommended alternatives for resolution of any differences
- *(k)* identification of the strengths and weaknesses that have a significant impact on the analysis
- *(l)* an assessment of the Capability Category of the SRs (i.e., identification of what Capability Category applies and is met for the SRs)

7.4.8.2 Resolution of Peer Review Team Comments

Resolution of peer review team comments shall be documented.

Exceptions to the alternatives recommended by the peer review team shall be justified.

Section 8
References

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NONMANDATORY APPENDIX A
COMPUTER CODES

A.1 COMPUTER CODES

A number of computer codes have been written to estimate consequences resulting from a release of radioactive materials into the atmosphere in support of Level 3 analyses. A partial list of these codes, along with references, is provided in Table A-1 to assist in code selection. Most of these codes were developed before the end of the 1980s.

Currently, a widely used code in the U.S. and internationally is MACCS2, which was developed by Sandia National Laboratories for the NRC. A newer version of the MACCS2 code is embodied in the WinMACCS code. Using the MACCS2 code as a basis, a list of code input choices is provided in Table A-2 to illustrate parameters used in a typical Level 3 consequence analysis. A list of output choices is provided in Table A-3.

The original consequence code developed in the US is CRAC, which was created to support the Reactor Safety Study (WASH-1400 [A.1]). The second-generation code was CRAC2, which was used, most notably, to calculate the consequences in the Sandia Siting Study.

The third-generation consequence code was MACCS, which was used in the landmark, NUREG-1150 [A.2] PRA of five U.S. nuclear power plants (NPPs). Primarily under DOE sponsorship, MACCS evolved into MACCS2, which remains in use today. The most recent version is called WinMACCS. However, WinMACCS is primarily a user interface, with an updated version of MACCS2 as the computational engine behind the scenes.

It is generally impractical and unnecessary to perform consequence analysis by hand or with simple tools, such as a spreadsheet. While the calculations are not difficult, the quantity of them needed to perform a full Level 3 analysis would be prohibitive without some kind of computer code. Level 3 PRA tools generally do not need to be of highest fidelity; rather, computational performance is very important because of the large volume of calculations that need to be performed and because the calculations most often need to be repeated a number of times during the overall analysis process.

Because the Level 3 consequence analysis tools have a relatively large number of inputs, it is important that the consequence analyst be properly trained and/or experienced before performing a Level 3 analysis. This is especially important when the application and associated decisions are highly important or have a high profile.

Finally, a PRA tool needs to be adequately documented. This can be done by means of a traditional user's manual, internal on-line documentation, or a combination of both. To be most useful, the documentation should offer practical advice to guide less experienced analysts through the process of performing a consequence analysis. To some extent, such documentation can reduce the need for an analyst to be well trained.

Table A-1 List of Consequence Codes Used in Nuclear Plant Applications

Code Name	History	Reference
WinMACCS	Improved version of MACCS2 with Windows interface, treatment of uncertainties, and some post-processing capabilities (currently supported by NRC). Used to support SOARCA.	K. McFadden, N. E. Bixler, L. L. Eubanks, and R. K. Haaker, "WinMACCS, a MACCS2 Interface for Calculating Health and Economic Consequences from Accidental Release of Radioactive Materials into the Atmosphere: User's Guide and Reference Manual for WinMACCS Version 3," to be published, Sandia National Laboratories (December 2009)
MACCS2	Level 3 consequence code developed for the NRC, widely used within the U.S. and internationally (currently supported by the NRC).	D. I.Chanin, M. L. Young, J. Randall, and K. Jamali, "Code Manual for MACCS2: Volume 1, User's Guide," NUREG/CR-6613, SAND97-0594, Sandia National Laboratories (1998)
MACCS	Level 3 consequence tool used in NUREG-1150 (not currently supported).	D. I. Chanin, J. L. Sprung, L. T. Ritchie, and H-N Jow, "MELCOR Accident Consequence Code System (MACCS), Volume I, User's Guide," NUREG/CR-4691, SAND86-1562, Sandia National Laboratories (1990)
CRAC2	Improved version of CRAC Code used in the Sandia Siting Study (not currently supported).	L. T. Ritchie, J. D. Johnson, and R. M. Blond, "Calculations of Reactor-Accident Consequences Version 2 CRAC2: Computer Code, User's Guide," NUREG/CR-2326, SAND81-1994, Sandia National Laboratories (1983)
CRAC	Original consequence code developed for WASH-1400 (the Reactor Safety Study) (not currently supported).	WASH-1400, "Reactor Safety Study: An Assessment of Accident Risks in U.S. Nuclear Power Plants, Appendix VI, Calculation of Reactor Accident Consequences," U.S. Nuclear Regulatory Commission (October 1975)

Table A-1 List of Consequence Codes Used in Nuclear Plant Applications (Cont'd)

Code Name	History	Reference
CRACIT	Similar to CRAC2 with Variable Wind and Evacuation Trajectory developed by PLG (now ABS Consulting).	K. Woodard, “The Enhanced CRACIT Computer Code and Insights Gained from Its Use,” presented to the Technical Committee on Computer Codes for the Probabilistic Assessment of Accident Consequences (1987)
CRACEZ	Consequence model developed by PLG with 3-D wind field and particle-in-cell dispersion.	K. Woodard, “Summary of the CRACEZ Consequence Model,” ABS Consulting (1994)
COSYMA	Consequence code developed in Europe.	G. N. Kelly, “COSYMA: A New Programme Package for Accident Consequence Assessment,” EUR 13028, Commission of the European Communities (1990)
PC COSYMA	Consequence code developed in Europe.	Health Protection Agency, UK (HPA), J. A. Jones et al., “PC COSYMA (Version 2): An Accident Consequence Assessment Package for Use on a PC,” EUR 16239, European Commission (1996)
ARANO	Consequence code developed in Finland (not currently supported).	S. Vuori, “Evaluation of Nuclear Power Plant Siting by Probabilistic Assessment of Environmental Impact,” Ph.D. thesis, U. of Helsinki (1978)
CONDOR	Consequence code developed in UK (not currently supported).	AEAT, BE, NRPB and BNFL, “CONDOR 2: A Probabilistic Consequence Assessment Code Applicable to Releases of Radionuclides to the Atmosphere,” AEAT-6271, NRPB-M1057, M/TE/GEN/REP/0088/00 (2000)
LENA	Consequence code developed in Sweden (not currently supported).	U. Baeverstam and O. Karlberg, “Lena P: A Probabilistic Version of the LENA Code Version 1.0,” Swedish Radiation Protection Institute (January 1993)
OSCAAR	Consequence code developed in Japan (currently supported by JAERI).	T. Homma and T. Matsunaga, “OSCAAR Model –Description and Evaluation of Model Performance,” Japan Atomic Energy Research Institute (2006)

Table A-1 List of Consequence Codes Used in Nuclear Plant Applications (Cont'd)

Code Name	History	Reference
UFOMOD	Consequence code developed in Germany (not currently supported).	J. Ehrhardt et al., “The Program System UFOMOD for Assessing the Consequences of Nuclear Accidents,” KfK 4330, Kernforschungszentrum, Karlsruhe, Germany (October 1988)
AI-RISK	Consequence code developed at LANL.	D. McFarlane and Y. C. Yuan, “AI-RISK: A Computer Program for Calculating Doses and Health Risks from Accidental Release of Nuclear Materials,” LA-UR-92-2636, Los Alamos National Laboratory (July 1992)

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2)

Input Type	Description
Geometry Data	
Spatial coordinate system representing the region surrounding the plume source	16 to 64 compass sectors 15 to 35 radial grid elements, usually spaced logarithmically 1 to 1600 km outer radius
Radionuclide Data	
Radionuclides	A sufficient list of radionuclides is required to adequately account for consequences. Older reactor consequence analyses used a standard list of 60 radionuclides with dose conversion factors based on ICRP 26 [A.3] and 30 [A.4], but nine additional daughters were implicitly accounted for. More recent consequence analyses account for 69 radionuclides with dose conversion factors from FGR-13 [A.5].
Radionuclide (chemical) groups	Each radionuclide belongs to a group of radionuclides that are assumed to behave similarly in terms of release and deposition. Assignment of radionuclide groups should generally be consistent with the Level 2 analysis. Typically, nine chemical groups are selected.
Radionuclide inventory	Radionuclide inventory should be consistent with the Level 2 analysis. Ideally, radionuclide inventory is calculated specifically for the plant or facility using a code like ORIGEN.
Decay-chain terminators	Daughter products that have a very long half-life or contribute insignificantly to consequences (including subsequent daughters) can be considered pseudo-stable (i.e., as though the daughter were a stable isotope). Decay-chain terminators may be required when the code has a limit on decay-chain length. A group of 27 pseudo-stable isotopes is self-consistent with older calculations that use 60 radionuclides; a group of 16 pseudo-stable isotopes is self-consistent with more recent calculations that use 69 radionuclides.

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2) (Cont'd)

Input Type	Description
Inventory scale factor	This scale factor allows the radionuclide to be scaled without needing to redefine all of the values. This is convenient when an inventory is being used for a similar reactor but with a different power rating. It can also be used as a simple way to convert units [e.g., to convert Curies (Ci) to Becquerels (Bq)].
Wet and Dry Deposition Data	
Wet and dry deposition	All radionuclides, except noble gases, are subject to wet and dry deposition.
Wet deposition	A wet-deposition model treats washout or rainout of particles and soluble gases.
Dry deposition	Dry deposition is treated in order to account for land contamination and long-term health effects. Older calculations have used a single deposition velocity to characterize the entire range of particle sizes; newer calculations account for the particle binning used in the Level 2 analysis. Typical values for deposition velocity are in the range of 0.01 to 10 cm/s, depending on particle size and density.
Dispersion Parameter Data	
For a Gaussian plume model, use spatially dependent dispersion parameters σ_y and σ_z. Provide σ_y and σ_z factors for each of the six Pasquill-Gifford stability classes.	For a Gaussian plume model, dispersion parameters can be functions of downwind distance or time. The dispersion parameters are different for each of the six (or seven) Pasquill-Gifford stability classes. Some newer models treat a continuous range of turbulent intensity using boundary layer theory. Some codes allow dispersion parameters to be entered as power-law functions or in tabular form. Either of these is acceptable, although tabular functions are generally more accurate for vertical dispersion, which does not behave as a power-law function.
Plume Meander Data	
Meander function	Dispersion measurements have generally been based on 10-minute releases. Releases longer than 10 minutes are potentially subject to greater dispersion through the mechanism called plume meander. Several plume meander functions have been proposed and are applicable under specific situations. The original MACCS2 model accounts for the effect of duration of release on plume meander. The Regulatory Guide 1.145 [A.6] model assumes a one-hour release but accounts for the effects of stability class and wind speed on plume meander. Under most circumstances, one of these models should be applied. Standard default parameters should be used.
Plume Rise Data	
Plume rise model	Most consequence codes incorporate one or more models to account for plume rise caused by buoyancy. The initial release height is usually specified by the Level 2 analysis. Additional plume rise is generally calculated using a Briggs model. MACCS2 offers two plume rise options; the improved model is recommended. Default parameters should be used.

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2) (Cont'd)

Input Type	Description
Wake Effects Data	
Building height	The building height should be set to the actual building height at the site. This may be the height of a reactor building, or, if the reactor building is overshadowed by an adjacent building, the taller building height should be used.
Area source	Initial dispersion parameters (σ_y and σ_z) specify the initial size of the plume as it emerges from the building wake. These parameters are proportional to the dimensions of the building. When the building has a footprint that is elongated in one dimension compared with the other, some judgment is required in defining the building width. A reasonable choice is to use the geometric mean of the maximum and minimum dimensions in the footprint.
Release Description Data	
Warning time	The reference time is reactor trip, which often corresponds closely with accident initiation. The assignment of warning time often depends on key timing results from the Level 2 analysis. For example, the emergency procedures may require that the plant declare a general emergency when the water level reaches the top of active core. Following the declaration of a general emergency, the local or state authorities notify the public to take action, either to evacuate or shelter in place. The elapsed time between reactor trip and public notification is the warning time. Note: it is convenient in some circumstances to choose warning time in some other way. For example, if warning time is set to zero, then the reference time for emergency response is the time of reactor trip rather than notification of the public.
Evacuation/Sheltering	Once protective actions have been called for, the parameters associated with evacuation (e.g., speed) or sheltering are used to determine population exposures.
Number of release segments	Most calculations have used one to four plume segments to treat the time dependence of release. While this is adequate, the current version of MACCS2 allows up to 200 plume segments. There are two reasons why a larger number of plume segments increases the fidelity of the calculation: 1. The timing of release is better approximated. 2. Wind shifts in the weather data (usually hourly) can be treated. Accounting for wind shifts increases fidelity and reduces peak doses, which reduces the possibility of overestimating the number of early fatalities.
Plume reference time	For purposes of calculating decay and timing of weather, MACCS2 characterizes the plume as though it were all at a single point. This point can be anywhere along the length of the plume. Generally, assigning the reference point to be at the midpoint provides the most accuracy. Shortening the duration of plume segments diminishes the importance of this parameter.
Plume delay	Plume delay is the time from reactor trip until the beginning of release for a plume segment. This parameter has to be greater than zero but can be several days depending on the accident sequence.
Release height	This is simply the initial height as which the plume is released. It must be at least 0 (ground level) and can be up to the height of the containment dome.
Plume duration	This is the release duration for each plume segment. This value is between 1 minute and 1 day, although a maximum of 10 hours is recommended when the MACCS2 plume meander model is used. Ideally, plume durations should be one hour or less to best account for the effect of wind shifts.

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2) (Cont'd)

Input Type	Description
Size distribution	Traditionally, a single particle size bin has been defined. Ideally, the particle size bins used in the Level 2 analysis should also be used in the Level 3 analysis. This allows a range of deposition velocities to be used, which increases fidelity.
Release fractions	Release fractions are fractions of the radionuclide inventory. They are specified for each chemical group and for each plume segment.
Release of daughters	Daughters that form during the interval between reactor trip and release can either be released using the release for the parent or for the daughter. While the daughter option is a better representation of the way release would actually occur, the parent option is generally more compatible with the Level 2 analysis. For this reason, the parent option is generally preferred.
Buoyancy Data	
Rate of energy release	The plume generally contains sensible heat that causes it to be buoyant. The latest version of MACCS2 provides two options to describe the rate of energy release in the plume: 1. rate of release of sensible heat (W) 2. mass flow rate (kg/s) and density (kg/m^3) of the effluent Either of these options should use data directly out of the Level 2 analysis. The second option better characterizes buoyancy resulting from the presence of hydrogen in the effluent.
Emergency Phase Description	
Duration of the emergency phase	The emergency phase is the phase during which the population follows emergency response measures, such as sheltering, evacuating, and relocating. The duration of the emergency phase generally needs to be long enough that all plumes released during the accident pass through and exit the grid. Typically, the emergency phase is 1 week.
Organs of risk	A set of organs is specified for which acute and/or latent cancer health effects are to be calculated. Organs that are not specifically treated for latent health effects are usually captured in a pseudo-organ called residual.
Acute (early) health effects	A set of parameters define the types of acute health effects to be treated and the risks to an individual of incurring those health effects from an exposure. In MACCS2, the risk to an individual is defined using a Weibull function, which has an S-shape for risk as a function of acute dose. The curve for each health effect is defined by three parameters: a dose threshold, a shape factor, and a dose for which 50% of the population is affected. Acute health effects can include both injuries and fatalities.
Latent-cancer health effects	A set of parameters define the types of latent-cancer health effects to be treated and the risks to an individual of incurring those health effects. The functional dependence of latent-cancer risk on dose is generally recognized to be linear at high dose rates; the functional dependence is very controversial at low dose rates. Most treatments of cancer risk include a dose and dose-rate effectiveness factor (DDREF). For low doses below a specific threshold [usually 0.2 Sievert (Sv)] received over a protracted period, the actual dose is divided by this factor before calculating cancer risk. Recommended values of DDREF range from 1 to 12. Furthermore, some health physicists and societies have suggested an annual and/or lifetime threshold dose below which incremental cancer risk is negligible. When these thresholds are applied, risk is estimated to be zero unless the dose exceeds the threshold. Once an effective dose is determined, a risk factor is then used to estimate cancer risk. Cancer health effects can include both occurrences (injuries) and fatalities, since not all cancers are fatal.

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2) (Cont'd)

Input Type	Description
Resuspension	Resuspension treats a set of mechanisms by which deposited particles can become airborne and thus be inhaled. Resuspension models generally treat resuspension to diminish with time. MACCS2 assumes an exponential decrease with time.
Cohort definition	A significant part of the treatment of emergency response is to define an appropriate set of cohorts. A cohort is a subset of the population that behaves in some fashion (e.g., evacuates promptly when emergency sirens are sounded). MACCS2 allows up to 20 cohorts to be defined. Cohorts are usually defined as a fraction of the overall population, but can be defined in a more general way.
Response actions	MACCS2 treats the evacuating public as having four distinct behaviors that are followed in order. The first is normal activity, which is following a normal daily routine involving some time spent indoors and some outdoors. The second is sheltering, one of the possible emergency responses. The third is evacuating, another of the possible emergency responses. The fourth is being removed from the dose calculations after having evacuated or relocated.
Response delays	MACCS2 uses a set of delays to establish the timing of each of the four behaviors. The delay times can be zero, which allows behaviors in the above sequence to be skipped.
Evacuee travel speeds	During evacuation, MACCS2 allows a very general specification of travel speeds, which can depend on time, location, and the presence or absence of precipitation.
Evacuation routing	MACCS2 allows for simple radial evacuation, in which evacuees move radially outward from the plant, or a network evacuation model, which allows for realistic treatment of evacuation routes.
Relocation	Some of the population that does not evacuate may nonetheless relocate if doses are too large. MACCS2 allows for two types of relocation. Hotspot relocation has a higher dose threshold and shorter relocation time; normal relocation has a lower dose threshold but a longer relocation time. This simulates the reality that priority would be given to those who would receive a larger dose if not relocated quickly.
Shielding	Depending on the type of activity, a member of the public receives some amount of shielding from radiation exposure. Shielding parameters are multipliers on the doses that would be received if an individual were directly exposed to the plume without any shielding. These factors depend both on activity and on dose pathway. Activities include normal activity, sheltering, and evacuating. Dose pathways include cloudshine, groundshine, inhalation, and deposition of particles onto exposed skin.
Long-Term Phase Description	
Duration	The duration of the long-term phase is often chosen to be consistent with the dose commitment period, which is 50 years.
Shielding	Analogous to the emergency phase, shielding factors are applied in the long-term phase to scale the doses that would have been received without shielding. Long-term shielding applies to the groundshine and inhalation pathways.
Habitability criterion	Long-term doses result from the population returning to live in areas that have been contaminated. In some cases, the areas have been decontaminated, but, nonetheless, some residual contamination remains. The habitability criterion determines the dose levels at which people return to their homes and thus has a significant effect on the overall doses received by the public.

Table A-2 Examples of Input Parameter Requirements in a Consequence Code (Based on MACCS2) (Cont'd)

Input Type	Description
Resuspension	The long-term treatment of resuspension is analogous to the treatment of resuspension during the emergency phase. Since resuspension diminishes over time, the magnitude of resuspension at the start of the long-term phase is lower than during the emergency phase and continues to diminish over the course of the long-term phase.
Groundshine weathering	Groundshine diminishes over time in the same way as resuspension. This phenomenon is referred to as groundshine weathering.
Compensation costs	MACCS2 assumes that there would be compensation costs for displaced population, either from evacuation or relocation. The compensation costs are similar to a per diem living expense.
Decontamination plan	MACCS2 allows for three decontamination plan levels, depending on the degree of contamination. Each plan level has a duration, a decontamination factor that reduces the initial contamination level, a cost to implement for farmland and nonfarmland, and invokes worker doses to accomplish. A set of parameters define each of these aspects of the treatment.
Property losses	MACCS2 treats economic losses associated with property through three mechanisms. These are loss of value due to depreciation, loss of use, and total loss if the property is too contaminated to be restored to use.
Permanent relocation cost	If part of the population has to be permanently relocated, a one-time cost for moving is included in the overall costs.
Wealth	The value of land and improvements to the land are used to determine whether it is economical to decontaminate property. When the cost of decontamination exceeds the value of the property, the property is condemned.

Table A-3 Examples of Output Information from a Quality Consequence Code

Output Type	Description of Output
Health effects cases	The number of health effects corresponding to early- or latent-cancer incidences or fatalities. May be specific types or totals for combined incidences or fatalities. For example: *(a)* incidences of thyroid cancer *(b)* fatalities from thyroid cancer *(c)* total latent cancer fatalities *(d)* early injuries for pneumonitis *(e)* total early fatalities
Population dose	The total dose to the population between specified radii. May be reported for various doses (e.g., effective dose and thyroid dose). For a SAMA or severe accident mitigation design alternative (SAMDA) analysis, this value is needed within a radius of 50 miles.
Population-weighted risk	Risk to the population between specified radii. Risk represents the conditional risk for a person within the specified boundaries receiving a health effect. Health effects are typically total early- or total latent-cancer fatalities.
Peak or centerline dose	Maximum dose to an individual as a function of distance from the point of release. Dose may be an effective dose or a dose to an individual organ, such as to the thyroid.
Economic costs	Costs resulting from an accident including evacuation/relocation costs, costs to decontaminate, loss of use costs, and condemnation costs. These costs are required for SAMA and SAMDA analyses for property within 50 miles of the plant.

A. 2 References

[A.1] WASH-1400, "Reactor Safety Study: An Assessment of Accident Risks in U.S. Nuclear Power Plants, Appendix VI, Calculation of Reactor Accident Consequences" U.S. Nuclear Regulatory Commission (October 1975)

[A.2] NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," U.S. Nuclear Regulatory Commission (December 1990)

[A.3] ICRP 26, "Recommendations of the International Commission on Radiological Protection," *Annuals of the ICRP*, Ann. ICRP 1 (3), International Commission on Radiological Protection (1977)

[A.4] ICRP 30, "Limits for Intakes of Radionuclides by Workers," *Annals of the ICRP,* Ann. ICRP 8 (4), International Commission on Radiological Protection (1982)

[A.5] FGR-13, "Cancer Risk Coefficients for Environmental Exposure to Radionuclides: Updates and Supplements," U.S. Environmental Protection Agency (2006)

[A.6] Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," U.S. Nuclear Regulatory Commission (November 1982, correction issued February 1983)