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DOE-STD-1020-YR
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DOE STANDARD

Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities

U.S. Department of Energy
Washington, D.C. 20585

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Foreword

Department of Energy (DOE) Standard (STD) 1020-2011 provides criteria and guidance for the analysis and design of facility structures, systems, and components (SSCs) that are necessary for implementing the requirements of DOE Order (O) 420.1C, *Facility Safety*, to ensure that the SSCs will be able to perform their intended safety functions effectively under the effects of Natural Phenomena Hazards (NPHs). This standard also provides criteria and guidance for the use of industry building codes and voluntary consensus standards in the NPH analysis and design of SSCs in DOE facilities. In particular, it provides criteria and guidance for:

- Establishing the performance requirements for SSCs in terms of parameters that define failure of their safety functions (e.g., the state of deformation or Limit State under seismic loads, flood water level relative to the location of a SSC that is vulnerable to inundation, etc.), and gradation of SSCs into more than one NPH design category based on the consequences of SSC failure when subjected to NPH events,

- Calculating maximum NPH demands on SSCs resulting from NPH events in terms of parameters that define failure of their safety functions, and

- Design (or, for existing facilities, design evaluation) of SSCs to ensure their ability to maintain required functionality when subjected to demands from NPH events.

The focus of this Standard is on the analysis and design of new facilities. For existing facilities, evaluations of seismic capabilities should have already been performed utilizing previous version of this and other related NPH standards. Use of this standard in any new NPH evaluations for existing facilities is not mandatory, but is recommended and is at the discretion of the Program Office.

Prior to this revision of DOE-STD-1020, DOE used the following DOE Guide (G) and Standards to support implementation of the NPH requirements of DOE O 420.1:

- **DOE G 420.1-2**, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear and Non-Nuclear Facilities*;
- **DOE-STD-1020-2002**, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*;
- **DOE-STD-1021-93 (Reaffirmed in 2002)**, *Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems, and Components*;
- **DOE-STD-1022-94 (Reaffirmed in 2002)**, *Natural Phenomena Hazards Site Characterization Criteria*; and
- **DOE-STD-1023-95 (Reaffirmed in 2002)**, *Natural Phenomena Hazards Assessment Criteria*.

Because of the recent development and issuance of several voluntary consensus standards by the nuclear industry professional organizations that address DOE NPH analysis and design needs, three of the listed standards have been superseded and the DOE NPH Guide has been cancelled with some information re-located to the new DOE-STD-1020-2011 as discussed below:

- **DOE G 420.1-2:** This guide is cancelled. Most of the guidance was no longer needed and any remaining applicable guidance was incorporated into this revision of DOE-STD-1020.
- **DOE-STD-1021-93:** This standard is superseded. The seismic categorization provisions of this standard are replaced by ANSI/ANS-2.26-2004, *Categorization of Nuclear Facility*

Structures, Systems, and Components for Seismic Design. The wind and flood hazard mitigation provisions are replaced by new criteria and guidance provided in this revision of DOE-STD-1020.

- **DOE-STD-1022-94:** This standard is superseded. The seismic site characterization provisions of this standard are replaced by ANSI/ANS-2.27-2008, *Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessment*, as specified in this revision of DOE-STD-1020. The wind and flood site characterization provisions are also given in this revision.
- **DOE-STD-1023-95:** This standard is superseded. The seismic hazard assessment provisions of this standard are replaced by ANSI/ANS-2.29-2008, *Probabilistic Seismic Hazards Analysis*, as specified in this revision of DOE-STD-1020-. The wind and flood hazards assessment provisions are also given in this revision.

The superseded standards will still be available for reference and use at existing facilities and can be found at the archived standards section of the Technical Standard Program web site.

In addition, this revision of DOE-STD-1020 provides supplemental criteria and guidance relative to seismic hazards (beyond and/or supporting that provided in the industry standards) and new criteria and guidance for analysis and design of SSCs for lightning, snow, and volcanic eruption events.

Throughout this standard, the word “shall" denotes actions that are required to comply with this standard. The word "should" is used to indicate recommended practices. The use of "may" with reference to application of a procedure or method indicates that the use of the procedure or method is optional.

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1.0 Introduction

1.1 Purpose

This Standard provides criteria and guidance for the analysis and design of facility structures, systems, and components (SSCs) that are necessary for implementing the requirements of DOE Order (O) 420.1C, *Facility Safety*, to ensure that the SSCs will be able to perform their intended safety functions effectively under the effects of Natural Phenomena Hazards (NPHs). This standard also provides criteria and guidance for the use of industry building codes and voluntary consensus standards in the NPH analysis and design of SSCs in DOE facilities.

1.2 Background

The earlier versions of this DOE standard have been directly providing NPH analysis and design methods, requirements and criteria to satisfy DOE NPH requirements. However, since the passage of the 1995 National Technology Transfer and Advancement Act (NTTAA) that encourages the use of industry building codes and voluntary consensus standards, DOE has actively participated with standards development organizations, (e.g., American Nuclear Society (ANS), American Society of Civil Engineers (ASCE)), to develop the following five voluntary consensus standards associated with the seismic and extreme winds design of nuclear facilities:

- ANSI/ANS-2.26-2004, *Categorization of Nuclear Facility Structures, Systems, and Components*;
- ASCE/SEI 43-05, *Seismic Design Criteria, for Structures, Systems, and Components in Nuclear Facilities*;
- ANSI/ANS-2.27-2008, *Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessment*;
- ANSI/ANS-2.29-2008, *Probabilistic Seismic Hazards Analysis*; and,
- ANSI/ANS-2.3-2011, *Standard for Estimating Tornado, Hurricane, and Extreme Straight- Line Wind Characteristics at Nuclear Facilities*.

The first four of these voluntary consensus standards were adopted by DOE, with some modifications as stated in DOE Standard (STD) 1189-2008, *Integration of Safety into the Design Process*, for seismic design of new facilities and major modifications of existing facilities, thereby replacing the seismic portions of:

- DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities.*
- DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems and Components*
- DOE-STD-1022-94, *Natural Phenomena Hazards Site Characterization Criteria,* and
- DOE-STD-1023-95, *Natural Phenomena Hazards Assessment Criteria.*

The use of criteria and guidance in DOE-STD-1020-2002, 1021-93, 1022-94 and 1023-94 for NPHs other than seismic was continued, in large part, with the criteria and guidance being consolidated, updated, and incorporated into this revision of DOE-STD-1020. , This revision of DOE-STD-1020 adopts the seismic voluntary consensus standards to make it consistent with the approach taken in DOE-STD-1189 and consolidates, updates, and incorporates criteria and guidance for other NPH that was included in the DOE NPH standards (i.e., DOE-STD-1020-2002, DOE-STD-1021-93, DOE-STD-1022-94, and DOE-STD-1023-95). These four standards are superseded by the new Standard 1020 and the voluntary consensus standards that it is adopting, but will still be available for reference and use at existing facilities and can be found at the archived standards section of the Technical Standard Program web site.

In addition, this revision provides new criteria and guidance for lightning, snow, and volcanic eruption hazards.

1.3 Applicability and Scope

This standard has the same applicability as Chapter IV of Attachment 2 in DOE O 420.1C, *Facility Safety*, i.e., it is applicable to all DOE facilities (owned and leased) and sites.

The focus of this Standard is on design of new facilities. Use of this standard in any new NPH evaluations for existing facilities is recommended, but it is at the discretion of the Program Office.

This standard addresses the following NPHs: earthquakes, extreme winds (inclusive of tornado, hurricane, and extreme straight line winds), floods, lightning, snow, and volcanic eruptions. Wildland fires that may result from certain NPHs are not addressed in this standard; these are addressed in DOE-STD-1066-2011, *Fire Protection Design Criteria*.

1.4 Overview and Organization

The NPH analysis and design process involves the following steps:

Step 1: Establishing the performance requirements for SSCs in terms of parameters that define failure of their safety functions (e.g., the state of deformation or Limit State under seismic loads, flood water level relative to the location of a SSC that is vulnerable to inundation, etc.), and gradation of SSCs into more than one NPH design category based on the consequences of SSC failure when subjected to NPH events.

Step 2: Calculating maximum NPH demands on SSCs resulting from NPH events in terms of parameters that define failure of their safety functions.

Step 3: Design (or, for existing facilities, design evaluation) of SSCs to ensure their ability to maintain required functionality when subjected to stresses from NPH events.

This Standard is organized as follows to address each of these areas.

Section 2 provides generic NPH criteria and guidance for Step 1 for establishing the NPH performance and gradation requirements for SSCs. Additional criteria and guidance for Step 1 specific to a NPH type are provided in Sections 3 through 8. These sections also provide criteria and guidance for calculating NPH demands (i.e., Step 2) and for SSC design (i.e., Step 3) for each of the NPH types, i.e.:

- Section 3 addresses Seismic Hazards
- Section 4 addresses Wind, Tornado, and Hurricane Hazards
- Section 5 addresses Flood, Seiche and Tsunami Hazards
- Section 6 addresses Lightning Hazards
- Section 7 addresses Snow Hazards
- Section 8 addresses Volcanic Eruption Hazards

Section 9 discusses criteria and guidance for evaluation and modification of existing facilities. Section 10 provides criteria and guidance for ensuring quality assurance and peer reviews.

Appendices A and B provide definitions and acronyms. Non-mandatory Appendices C through E provide supplemental information on flood and wind evaluations.

2.0 NPH Performance and Graded Requirements for SSCs

2.1 Background and Overview

ANSI/ANS-2.26-2004 provides a process for determining a “Seismic Design Category” (SDC) and “Limit State (LS)” that establishes performance expectations for SSCs when subjected to seismic (i.e., earthquake-related) hazards. A LS defines the maximum deformation level that the SSC may undergo under seismic loads and still perform its intended safety function. SSCs are graded into five SDCs based on the consequences of SSC failure or the SSC reaching its LS. It is important to note that the LS defines SSC failure from seismic loads only, and it is not applicable to other NPHs.

For other NPHs (e.g., wind-related hazards, flood-related hazards), deformation-related SSC failure definition shall be consistent with the design codes being used. For example, for wind-related hazard design, SSC failure definition shall be consistent with that provided in ASCE/SEI 7-10. However, the hazard consequence evaluation process and dose criteria by which SDCs are determined are also applicable for selecting design categories for other NPHs. This standard endorses the use of the ANSI/ANS-2.26-2004 process for determining a design category for other NPHs.

The remainder of Section 2 describes the overall process for establishing SSC performance and graded requirements. Additional details are provided in each NPH-specific section (i.e., Sections 3 through 8).

2.2 General Criteria and Guidance for Establishing Design Categories

The NPH design category of an SSC establishes the frequency or its inverse, the return period, of the NPH event to which the SSC will need to be designed; or, for existing facilities, to which the SSC design will need to be evaluated. This NPH frequency or the return period, in turn, defines the level or size of the NPH.

2.2.1 The level or size of the design or evaluation basis NPH is based on the significance of the SSC for protection of workers and the public. For example, for seismic design of SSCs important for the protection of the public against high radiation doses, the return period for the design basis earthquake (DBE) will be much higher (i.e., the peak ground acceleration will be high) than that for SSCs whose failure does not result in any significant offsite consequences to the public.

2.2.2 Consistent with ANSI/ANS-2.26-2004, SSCs shall be given a design category (i.e., design category 1 through 5) for seismic, wind, flood, and volcanic eruption (e.g., ashfall) NPHs. For lightning protection, since data on the level or the size of lightning events and their frequency of occurrence are not available, only two design categories shall be specified, one category for SSCs that may not perform their safety functions when subjected to a lightning event, and the other category for SSCs that can perform their safety function when subject to lightning events.

2.2.3 For the seismic, wind, flood, and volcanic eruption (e.g., ashfall) NPHs, design categorization of an SSC shall be based on the severity of unmitigated consequences of its failure of safety function. Unmitigated failure consequences shall be determined in accordance with applicable provisions of DOE-STD-3009-2006, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, and DOE-STD-1189-2008.

2.3 General Criteria and Guidance for Defining Failure Condition

For different SSCs the “failure condition” (i.e., condition where the SSC cannot perform its safety function) will depend upon the safety function being performed. An SSC failure condition shall be defined using an approach consistent with ANSI/ANS-2.26-2004 for NPHs, and the guidelines given in this DOE standard.

2.3.1 For seismic hazard evaluations, consistent with ANSI/ANS-2.26-2004, the failure of an SSC shall be defined in terms of its LS or permissible deformation limit from safety function considerations.

2.3.2 For wind-related hazard evaluations in Section 4, except for evaluating tornado or wind borne missile impacts, and for other NPH evaluations in Sections 5 through 8, an SSC failure shall be defined in terms of the permissible stress, strain, or deformation given in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*; the provisions of which shall be used in designing the SSCs.

2.3.3 The computed stress, strain, or deformation in the SSC, when subjected to wind-related and flood-related hazards, shall not exceed the threshold value of any of these parameters at which the SSC fails to perform its safety function. For example, an SSC designed using the permissible stress criteria of ASCE/SEI 7-10, shall not deform in excess of the deformation limit at which the SSC cannot perform its safety function, or the deformation limit at which the SSC can compromise the safety function of another SSC.

2.3.4 When subjected to certain NPHs, an SSC can fail, not only because of excessive stress, strain, or deformation, but also due to other modes of failure (e.g., inundation during a flood, explosion due to tornado atmospheric pressure change). These failure modes shall also be considered in the hazard evaluation.

2.3.5 To ensure that proper failure criteria is developed (e.g., LS selected for determining the permissible maximum stress, strain, deformation, or displacement is consistent with the safety function(s) of the SSC as determined from hazard and accident analyses), the following professionals should work together and evaluate the functional requirements of the SSC and its subcomponents in relation to their modes of failure:

i) Safety Analyst who is responsible for hazard and accident analyses;

ii) NPH Design Engineer who is responsible for NPH design, and for coordinating the selection of SSC LS or failure deformation level and SSC NPH design category; and,

iii) Equipment Expert who is responsible for the mechanical and electrical design of the equipment.

3.0 Criteria and Guidelines for Seismic Design

This section of the standard provides criteria and guidance for analysis and design of SSCs for mitigating seismic hazards.

3.1 Seismic Design Categorization and Limit States

3.1.1 The guidelines and criteria for design categorization and Limit States of SSCs subjected to seismic hazards shall be the same as those in ANSI/ANS-2.26-2004 except that consequence evaluation criteria shall be as defined in Table 3-1 (i.e., categorization guidance in terms of unmitigated dose consequences given in Table 3-1 for SDC-1, SDC-2, and SDC-3 SSCs shall take precedence over those in Table A.3 of ANSI/ANS-2.26-2004).

Table 3-1.
Establishment of SDC Based on
Unmitigated Consequences of SSC Failures in a Seismic Event

	Unmitigated Consequence of SSC Failure from a Seismic Event	
Category	Collocated Worker	Public
SDC-1	Dose < 5 rem	Not applicable[1]
SDC-2	5 rem < dose < 100 rem	5 rem < Dose < 25 rem
SDC-3	dose > 100rem	dose > 25 rem

Table notes: [1] A Hazard Category 1, 2, or 3 nuclear facility with consequences to a collocated worker from failure of an SSC in a seismic event will require that SSC be classified as SDC-1 at a minimum. Therefore, a public criterion for SDC-1 is not needed.

[2] As noted in ANSI/ANS 2.26-2004, the SDCs used in this Standard and in this table are not the same as the SDCs referred to in the International Building Code (IBC).

3.1.2 No higher designations than safety significant or SDC-3 design requirements are judged to be necessary for collocated worker protection because (in addition to design features) site training and site emergency procedures provide for adequate protection for workers. Only in the case of an in-facility worker who must remain in the facility for safe shutdown or other safety-related purpose should SDC-3 be considered for SSCs required for protection of that worker. In that case, the mitigative effects of personal protective equipment may also be considered. Design effort should give priority to engineered design features over PPE in such a circumstance.

3.1.3 For seismic design purposes, SDC-1 SSCs having Limit State A shall be considered equivalent to Risk Category II of ASCE/SEI 7-10, and SDC-2 SSCs having Limit State B shall be considered equivalent to Risk Category IV.

3.1.4 For SDC-1 and SDC-2 SSCs having safety functions requiring other Limit States, they shall be designed following ASCE/SEI 7-10 provisions for Risk Category II and Risk Category IV, respectively, except as shown in Table 3-2, which replaces the table in Appendix A.1 of DOE-STD-1189-2008. In this table, the R values given in ASCE/SEI 7-10 has been modified to account for the difference in the limit states achieved by ASCE/SEI 7-10 and the Limit States A, B, C, and D defined in ANSI/ANS 2.26-2004 and ASCE/SEI 43-05. Following ASCE/SEI 7-10, the term “Occupancy Category” used in ASCE/SEI 7-05 and in the table in Appendix A.1 of DOE-STD-1189-2008 has been substituted with the term “Risk Category.”

Table 3-2

Response Modification Coefficients for Seismic Design of SDC-1 and SDC-2 SSCs

SDC	Limit State			
	A	B	C	D
1	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a = R^{(1)}$	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a = R/1.25$ $R_a > 1.0^{(2)}$	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a = R/1.5$ $R_a > 1.0^{(3)}$	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a = 1.0^{(4)}$
2	ASCE/SEI 7-10, Use Risk Category IV, I = 1.5 $R_a = 1.25R$	ASCE/SEI 7-10, Use Risk Category IV, I = 1.5 $R_a = R$	ASCE/SEI 7-10, Use Risk Category IV, I = 1.5 $R_a = R/1.2$ $R_a > 1.0^{(3)}$	ASCE/SEI 7-10, Use Risk Category IV, I = 1.5 $R_a = 1.0^{(4)}$

Table notes: (1) R = Response Modification Coefficient given in ASCE/SEI 7-10. R_a = Actual (reduced) Response Modification Coefficient to be used in the design substituting R values given in ASCE/SEI 7-10 to account for the difference in the limit states achieved by ASCE/SEI 7-10 and the Limit States A, B, C, and D defined in ANSI/ANS-2.26-2004 and ASCE/SEI 43-05

(2) R_a need not be less than (F_μ /DF) given in ASCE/SEI 43-05 for SDC-3 SSCs having Limit State B where F_μ is the inelastic energy absorption factor and DF is the Design Factor

(3) R_a need not be less than (F_μ /DF) given in ASCE/SEI 43-05 for SDC-3 SSCs having Limit State C

(4) R_a need not be less than (1.0 /DF) given in ASCE/SEI 43-05 for SDC-3 SSCs

3.2 Selection of Design Basis Earthquake (DBE) Return Period to Approximately Meet Target Performance Goal

3.2.1 For SDC-3 through SDC-5 SSCs, Design Basis Earthquake (DBE) return periods given in ANSI/ANS-2.26-2004 and ASCE/SEI 43-05 shall be used to determine the seismic ground motion applicable for the facility site.

3.2.2 For SDC-1 and SDC-2 SSCs, the DBE return period on which the seismic provisions of ASCE/SEI 7-10 are based shall be used.

3.3 Site Characterization

3.3.1 For SDC-3 through SDC-5 SSCs, site characterization for determining the data necessary for performing a site-specific Probabilistic Seismic Hazard Assessment (PSHA) shall be performed following the requirements given in ANSI/ANS-2.27-2008. In addition, the following criteria shall be satisfied:

i) Table 1 of ANSI/ANS-2.27-2008 states that for SDC-3, SDC-4, and SDC-5 design response spectra, earthquake sources contributing > 5% to the hazard at a site shall be characterized. For DOE purposes, earthquake sources contributing >1% to the hazard shall be characterized.

ii) Table 1 of ANSI/ANS-2.27-2008 column two is labeled "Maximum Considered Earthquake (MCE) spectral response acceleration," providing a range of spectral response accelerations for low, moderate and high seismic environments. For DOE purposes, and for consistency with terminology in ASCE/SEI 43-05, this column heading shall be read to mean, "Spectral response acceleration at 1 E-4 annual probability of exceedance."

iii) Section 4.4 of ANSI/ANS-2.27-2008 is titled "Characterization for site response analysis." When applying this section to DOE facilities, the contents of ANSI/ANS-2.29-2008 Section 5.4, "Site response assessment," shall also be applied.

3.3.2 For SDC-1 and SDC-2 SSCs, site characterization shall be performed in accordance with ASCE/SEI 7-10 to obtain the data necessary for site classification, and for determining site soil properties necessary for designing the SSCs. If applicable, site characterization activities shall also include the collection of data necessary to perform soil-structure interaction and the development of site-specific ground motion.

3.4 Probabilistic Seismic Hazard Analysis

3.4.1 For facilities having SDC-3 through SDC-5 SSCs, provisions of ANSI/ANS-2.29-2008 shall be used for performing site-specific PSHAs, with the following exceptions:

i) In specifying a lower-bound magnitude as required by Section 5.1.1 of ANSI/ANS-2.29-2008, "Lower-bound magnitude," the guidance in Electric Power Research Institute Technical Report 1012965, *Use of the Cumulative Absolute Velocity in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard Analysis*, shall be considered.

ii) If any of the provisions given in Section 5.4 of ANSI/ANS-2.29-2008, titled "Site Response Assessment," is in conflict with any provision given in Section 2.3 of ASCE/SEI 43-05, the provision given in ASCE/SEI 43-05 shall be used. .

3.4.2 For facilities having only SDC-1 and SDC-2 SSCs, it is not necessary to perform a PSHA for determining a site-specific ground motion. However, if a site-specific ground motion is used, or if it is required, the provisions of Section 11.4.7 and Section 21 of ASCE/SEI 7-10 shall be used; or a PSHA shall be performed in accordance with ANSI/ANS-2.29-2008 to determine the site-specific ground motion.

3.5 Building and Equipment Response Analysis to Determine Seismic Demand

3.5.1 For SDC-3 through SDC-5 SSCs, provisions of ASCE/SEI 43-05 and ASCE/SEI 4-98 shall be used for determining seismic demands, based on the following considerations and exceptions::

i) Design Basis Seismic Ground Motion: The development of the design basis seismic ground motion shall be in accordance with the requirements of Section 2 of ASCE/SEI 43-05. Seismic input requirements given in Section 2 of ASCE 4-98 shall be used only to the extent these are consistent with the requirements of Section 2 of ASCE/SEI 43-05. However, since ASCE 4 and ASCE 43 are developed and updated by the same ASCE committee, when ASCE 4 is revised, the revised seismic input requirements shall take precedence over those in ASCE 43-05.

ii) Seismic Soil-Structure Interaction :The requirements of Section 3.3 of ASCE 4-98 shall be followed, except that the wave incoherence provision given in Section 3.3.1.10 shall not be used. Due to the complexity of the SSI formulation of the incoherent wave field, simple models to estimate foundation motion, including the effects of incoherence, cannot be used. If any credit for incoherent motion is taken, it will require case-by case detailed justification. When ASCE 4 is revised, the revised soil-structure interaction analysis requirements, including those related to incoherent motion, shall be used.

iii) Dynamic Response Analyses and Generation of In-Structure Response Spectra: Requirements given in ASCE 4-98 shall be used only to the extent these are consistent with the requirements of ASCE/SEI 43-05. However, since ASCE 4 and ASCE 43 are developed and updated by the same ASCE committee, when ASCE 4 is revised, the revised requirements shall take precedence over those in ASCE 43-05,.

3.5.2 The ASCE/SEI 7-10 provisions applicable for Risk Category II and Risk Category IV SSCs shall be used for determining seismic demands of SDC-1 and SDC-2 SSCs. However, the R values given in ASCE/SEI 7-10 shall be modified as shown in Table 3-2 of this standard to account for the difference in the limit states achieved by ASCE/SEI 7-10 and the Limit States A, B, C, and D defined in ANSI/ANS-2.26-2004 and ASCE/SEI 43-05.

3.6 Building and Equipment Capacity Evaluation

3.6.1 For SDC-3 through SDC-5 SSCs, provisions of ASCE/SEI 43-05 shall be used for determining SSC capacity to withstand the seismic demands combined with other applicable concurrent loads.

3.6.2 For SDC-1 through SDC-2 SSCs, provisions of ASCE/SEI 7-10 shall be used for determining SSC capacity to withstand the seismic demands combined with other applicable loads.

3.6.3 To evaluate the adequacy of the SSC to withstand the seismic demands combined with other applicable concurrent loads, the ratio of the total demand, D, to SSC capacity, C, shall be computed. The computed D/C value shall not exceed unity.

4.0 Criteria and Guidelines for Wind, Tornado, and Hurricane Design

This section provides criteria and guidance for design and evaluation of SSCs for mitigating extreme wind hazards (i.e., extreme straight-line winds, rapid atmospheric pressure changes (APCs) from tornadoes, tornado missiles, hurricanes, and hurricane missiles). It provides guidance and criteria for:

- Determining a Wind Design Category (WDC) of an SSC based on the severity of SSC failure consequence (Section 4.1);
- Collecting wind speed data at DOE sites for which site-specific data related to wind hazards, tornado, and hurricane are required (Section 4.2);
- Performing Probabilistic Wind Hazard Assessments (PWHAs) on the basis of which design parameters related to the wind-related hazard can be determined (Section 4.3);
- Designing SSCs to mitigate the effects of wind-related hazards (Section 4.4).

SDC-1 and SDC-2 SSCs shall be designed for extreme wind hazards using the criteria given in ASCE/SEI 7-10 for Risk Category II and Risk Category IV facilities, respectively. Accordingly, unless specifically mentioned, the provisions given in Subsections 4.2 through 4.5 are only applicable to WDC-3, WDC-4, and WDC-5 SSCs.

For sites with WDC-3, WDC-4, and WDC-5 SSCs, site-specific design parameters for wind related hazards (e.g., wind speed, missile characteristics) shall be determined either using the guidelines and criteria provided in this section, or following the guidelines and criteria provided in ANSI/ANS 2.3-2011, *Standard for Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites*, as supplemented here in this section.

4.1 SSC Categorization for Wind Design

The design categorization process and criteria given in ANSI/ANS-2.26-2004 for seismic hazards shall also be used for wind design categorization as described below, and as previously described in Section 2.

4.1.1 Wind design categorization shall be based on the severity of unmitigated failure consequences resulting from all wind-related hazards which include extreme straight-line winds, hurricane winds, tornado winds, tornado APC, tornado-generated missiles, and hurricane-generated missiles, that are applicable to the DOE site and facility.

4.1.2 The failure of safety function of some SSCs, when subjected to a wind-related hazard, can occur not only because of excessive deformation or distortion, but also as a result of intrusion of windborne water into or onto the SSC. Such water intrusion-related failure modes shall be accounted for in determining SSC failure consequences in the selection of SSC WDC and related SSC design methods and criteria. See Section 5.0 for flood, seiche and tsunami hazards.

4.1.3 The failure of SSCs resulting from explosions of structures caused by rapid APCs from tornado passage shall also be accounted for.

4.1.4 In addition to rupture, instability, deformation-related or distortion-related failure modes of the SSCs, potential failure modes resulting from windborne water (e.g., shorting or malfunctioning of an electric circuit or equipment) shall also be accounted for in determining unmitigated failure consequences.

4.1.5 Barriers and other SSCs, that are provided for wind or missile protection of SSCs with safety functions, shall be placed in a WDC category equal to or higher than the category of the SSC to be protected. These protective SSCs, or barriers, shall be designed using stress, strain, or deformation limits appropriate for the protective function and the failure mode of the barrier. For example, a barrier intended to protect a WDC-3 SSC from a windborne missile impact shall perform its protective safety function even if it is deformed beyond its yield or rupture limit. The barrier may be designed accordingly, although it will be stressed beyond the stress permissible in ASCE/SEI 7-10. On the other hand, if the safety functions of the barrier require that it shall not deform beyond a deformation limit that corresponds to a stress much less than the stress permissible in ASCE/SEI 7-10, it shall be designed to the lower deformation criterion; even though this criterion will be stricter than the permissible criterion of ASCE/SEI 7-10.

4.1.6 The site-specific wind-related hazard data collection and PWHA shall be based on the highest WDC category of the SSCs at the site.

4.2 Site Characterization for Wind-Related Hazard Design

4.2.1 General Requirements

4.2.1.1 Unless the design basis wind-related hazard parameters are determined following the guidelines and criteria given in Section 4.3.3, sites which have facilities with WDC-3, WDC-4, or WDC-5 SSCs shall be characterized for all wind-related hazards following the guidelines and criteria provided in this section (i.e., Section 4.2).

4.2.1.2 The extent and the quality of meteorological data that needs to be collected to characterize wind-related hazards shall meet the requirements of ASCE/SEI 7-10 for determining the design basis wind speed and APC from tornado passage.

4.2.1.3 Guidance on meteorological monitoring programs can be found in DOE O 458.1, *Radiation Protection of the Public and the Environment*, and ANSI/ANS-3.11-2010, *Determining Meteorological Information at Nuclear Facility Sites*.

4.2.1.4 For sites with WDC-3, WDC-4, and WDC-5 SSCs, if the design basis wind-related hazard parameters are determined following the guidelines and criteria given in Section 4.3.3, site wind hazard characterization shall be performed following the guidelines and criteria provided in ANSI/ANS 2.3-2011.

4.2.1.5 Sites with only WDC-1 and/or WDC-2 SSCs shall be characterized following the requirements of ASCE/SEI 7-10. For these sites, data necessary for defining the ASCE/SEI 7-10 parameters needed to design the SSCs shall be collected.

4.2.2 Site Description

4.2.2.1 For sites using site-specific PWHAs (see Section 4.3), data and information on the geographical location of the facility on the DOE site necessary for estimating the distance from its location to the potential wind borne missile sources, and sources of hazardous and radioactive materials that may adversely affect the safety and health of the facility workers and the safety functions of SSCs, shall be collected.

4.2.2.2 Data for defining the size and orientation of the major facilities at the site, if necessary for determining probabilistic tornado wind speeds and for evaluating tornado missile hazards (e.g., when PWHA is performed using hazard models referenced in Appendix E), shall be collected.

4.2.2.3 A general location map to clearly define the boundary of the site and to show the distances from the site to natural and anthropomorphic features pertinent to being affected by wind-related hazards (e.g., mountains, rivers, lakes, oceans, streams, dams, levees) shall be developed.

4.2.2.4 A detailed mapping of topographic, hydrologic, and surface features, as appropriate, for the particular site conditions, with scales and contours suitable for wind-related hazard assessment shall be performed. The topographic map shall also show the character of surface drainage patterns and the topographic elevation of the site relative to nearby hydrologic features (e.g., rivers, streams, lakes, local surface drainage channels, ponds, springs, sinks) at the site.

4.2.3 Meteorological Data

The sources of atmospheric NPHs to be characterized shall include extreme straight-line winds, hurricane winds, tornado winds and APCs caused by tornadoes. Guidelines and criteria for collecting meteorological data to be used in a site-specific PWHA are provided in the following subsections.

4.2.3.1 Regional Climatology Description and History

a) The general climate of the region shall be described with respect to the types of topographic influences, general airflow patterns, temperature and humidity, precipitation, and relationships between regional atmospheric conditions and local meteorological conditions.

b) Regional extreme climatology history shall be reported with dates, event descriptions, and related information on their effects.

c) This information can generally be located in the Annual Site Environmental Report (ASER) developed to meet DOE O 450.1A, *Environmental Protection Program,* and requirements at each DOE site.

d) This information can also be located in Environmental Impact Statements (EISs) that have been prepared for the site or in Programmatic Environmental Impact Statements (PEISs) in which the site is one of the possible locations for the new mission.

4.2.3.2 Wind Data Collection

a) Wind data shall be collected to characterize three types of wind-related hazards:

   i) Straight-line winds;

   ii) Hurricane winds; and

   iii) Tornado winds.

b) Data sets of historical extreme winds shall be obtained from weather stations that are close enough to sites to spatially represent the site conditions. If more than one station is available, they may be combined, provided they represent the same conditions as those at the site. Specific guidance on spatial representativeness can be located in ANSI/ANS-3.11-2010, *Determining Meteorological Information at Nuclear Facilities*.

c) Guidelines and criteria for site-specific characterization of each of these three types of wind-related hazards are provided in the following three subsections.

4.2.3.2.1 Straight-Line Wind Data

Straight-line winds are non-rotating winds such as those occurring in thunderstorms and during frontal passages. This type of wind data shall be collected at locations near the site. Onsite meteorological data shall be collected, if available, per guidance in ANSI/ANS-3.11-2010, DOE O 458.1, and in Chapter 4 of DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, and meet the following six criteria:

a) There shall be at least ten continuous years of annual extreme wind speed records. However, if longer periods of record exist, use the entire period.

b) The elevations at which wind speeds are recorded shall be 10 meters (33 feet) above ground. The measurement elevation of these wind speeds, if not 10 meters (since wind speed varies with height in the Planetary Boundary Layer (PBL)), shall be identified and the recorded wind speeds shall be corrected using acceptable logarithmic wind height conversion methods.

c) The type of wind speed parameter recorded over time shall be specified (e.g., fastest-mile, peak speed, 3-second gust speed, etc.).

d) The recorded wind speeds shall be obtained from anemometers located in flat open terrain, if possible.

e) It is possible to utilize meteorological data from onsite stations for which less than ten years of records exist if there are a sufficient number of historical records from nearby National Weather Service (NWS) stations, within a similar topographic environment.

f) In the absence or lack of sufficient onsite wind record data, it is possible to utilize data collected by federal, state, and local agencies for stations close to the site (i.e., generally within 50 km) and located in a same wind environment. It should be noted that stations close to, but separated by mountainous ranges from the site, may not qualify.

4.2.3.2.2 Hurricane Wind and Barometric Pressure Data

Hurricane winds are rotating winds covering a large geographical area, with spatial and temporal variability in wind intensities. Hurricane-prone regions of the continental U.S are located along the coastal areas since hurricanes draw their energy from the oceans or other large warm water bodies (e.g., Gulf of Mexico). For sites in hurricane-prone areas and for which no up-to-date site-specific PWHA has been performed, the meteorological data of past historical hurricanes within 400 km (250 miles) from the site shall be collected, including:

a) Location of hurricane tracks, include information on longitude and latitude, with landfall locations;

b) Life-cycle hurricane intensity history, inclusive of Saffir-Simpson scale;

c) Reported minimal central barometric pressure near the coast or at point of landfall; and,

d) Reported maximum translational and rotational wind speeds near the coast or at point of landfall.

Sources of data on hurricanes are available from the National Hurricane Center (NHC), Miami, FL, and the National Climatic Data Center (NCDC), Asheville, NC.

4.2.3.2.3 Tornado Wind and Tornado APC Data

Tornado winds are violently rotating winds which can reach speeds in excess of 320 km/hr (200 mph). Midwestern states, especially Oklahoma and its neighboring states, have the greatest number of historically-recorded tornadoes. A secondary maximum of tornadoes occur in the Southeastern United States. For sites in tornado-prone areas and for which no up-to-date site-specific PWHA has been performed, the following data shall be collected for tornadoes striking within 500 km (310 miles) from the DOE site or reservation:

a) Tornado track, including latitude and longitude;

b) Tornado intensity using the Enhanced Fujita (EF) scale;

c) Tornado length and width; and,

d) Data and information necessary for characterizing potential tornado wind borne missiles (e.g., weight, size, and shape). See *Estimating Probabilities of Extreme Floods, Methods and Recommended Research* for additional guidance.

Sources of data on tornadoes are available from the National Severe Storms Forecast Center (NSSFC), Norman, OK; National Oceanic and Atmospheric Administration (NOAA), and the NCDC, Asheville, NC.

4.3 Probabilistic Wind Hazard Assessment and Determination of Wind Design Parameters

4.3.1 General

4.3.1.1 For sites which have facilities with WDC-3, WDC-4, or WDC-5 SSCs, unless ANSI/ANS-2.3-2011 provisions are used, a site-specific PWHA shall be performed and the design basis wind-related hazard parameters shall be determined using guidelines and criteria given in Section 4.3.2.

4.3.1.2 Sites for which ANSI/ANS-2.3-2011 provisions are used, the design basis wind-related hazard parameters shall be determined using the guidelines and criteria provided in Section 4.3.3.

4.3.2 Sites Using Site-Specific PWHA

Wind-related hazard design parameters for WDC-3, WDC-4, and WDC-5 SSCs at a DOE site or reservation shall be determined based on a PWHA using the guidelines and criteria provided in paragraphs a) through h) and Table 4-1 of this subsection. The PWHA shall be based on site-specific data related to wind-related hazards that have been collected in accordance with Section 4.2. The following criteria shall be considered:

4.3.2.1 A PWHA shall be performed for each of the three types of wind-related hazards, as appropriate:

i) Extreme straight-line winds;

ii) Hurricane winds; and,

iii) Tornado winds.

4.3.2.2 Extreme straight-line winds are non-rotating caused by air mass thunderstorms and frontal passages. However, both tornadoes and hurricanes have translational and rotational wind components. The applicability and potential for all three types of wind-related hazards shall be determined in the PWHA considering the geographical location of the DOE site or reservation.

4.3.2.3 In addition to the extreme wind-related hazard assessment for tornadoes that would provide design basis tornado wind speed, the tornado hazard assessment has additional components that are specific to this type of meteorological phenomenon. The design basis APC shall also be determined and shall characterize potential site-specific tornado windborne missiles (i.e., weight, size, shape, probable horizontal and vertical velocity); the latter based on the design basis tornado wind speed corresponding to the WDC of the SSC. In the absence of information on site-specific APC and tornado windborne missiles, values recommended in Section 4.3.3 shall be used.

4.3.2.4 The PWHA results shall include a mean wind-related hazard curve (i.e., wind speed at the site as a function of mean return period in years).

4.3.2.5 The PWHA method used shall be consistent with the prevailing industry practice, and shall use the latest available occurrence data considering the uncertainties therein. Appendix E provides additional guidance and recommendations on performing a PWHA.

4.3.2.6 The PWHAs for extreme straight-line winds and hurricanes may be combined to produce a single straight-line wind-related hazard curve by assuming that the two types of winds are mutually-exclusive events. This is a very reasonable assumption since the meteorological conditions causing them are very different and their simultaneous occurrence is of very low probability (e.g., frontal passages would likely steer hurricanes away from the site).

4.3.2.7 The design basis extreme straight-line wind, tornado wind, and hurricane wind shall be based on a mean return period as depicted in Table 4-1.

Table 4 -1
Mean Return Periods for Design Basis Wind Speeds for WDC-3, WDC-4, and WDC-5 SSCs

WDC**	**Design Basis Mean Return Period in Years**		
	Extreme Straight-Line Wind	**Hurricane***	**Tornado****
WDC-3	2,500	2,500	50,000
WDC-4	5,000	5,000	125,000
WDC-5	10,000	10,000,000	10,000,000

***** For hurricane-prone areas (i.e., near the Gulf of Mexico and Atlantic coast) only.

** Tornado wind hazards need not be considered if the straight-line wind speeds are greater than tornado wind speeds at the design basis return periods tabulated above, see ANSI/ANS-2.3-2011 *"Standard for Estimating Tornado, Hurricane, and Extreme Straight-line Wind Characteristics at Nuclear Facility Sites"* for additional information.

4.3.3 Sites Using ANSI/ANS-2.3-2011

For sites using ANSI/ANS-2.3-2011, wind-related hazard design parameters for WDC-3, WDC-4, and WDC-5 SSCs for a DOE site shall be determined as specified here in this subsection:

i) The extreme straight-line wind, tornado wind, and hurricane wind hazard curves, as shown in Figures 3.1-2 through 3.1-4 and in Table 3.1-2 of ANSI/ANS-2.3-2011, as applicable for the region, which is graphically shown in Figure 3.1-1 of ANSI/ANS-2.3-2011, shall be used to determine the design basis wind speeds.

ii) The characteristics of tornado and hurricane borne missiles, shown in Table 4-1 of ANSI/ANS-2.3-2011, shall be used.

iii) SSCs that have the potential to be adversely affected by the tornado APC and the impact of missiles resulting from the design basis tornado and hurricane shall be evaluated using the APC values and the missile characteristics given in Tables 3.2-1 and 4-1 of ANSI/ ANS-2.3-2011.

4.4 SSC Design and Evaluation to Mitigate Wind-Related Hazards

4.4.1 General Design Criteria

4.4.1.1 An SSC that may fail to perform its safety functions when subjected to water intrusion or submergence, or wind borne missiles resulting from wind-related hazards, shall be protected either by barriers designed to withstand the effects of wind-related hazards, or by placing the SSCs in a location that precludes missile impact, water intrusion, or submergence.

4.4.1.2 An SSC that may fail to perform its safety function because of structural deformation when subject to the adverse effects of wind-related hazards shall be designed based on the guidelines and criteria provided in Subsections 4.4.2 through 4.4.5.

4.4.2 Design of WDC-3, WDC-4, and WDC-5 SSCs

4.4.2.1 WDC-3, WDC-4, and WDC-5 SSCs shall be designed in accordance with the criteria and methodology given in ASCE/SEI 7-10 to withstand the applicable design basis wind speeds, APCs, and tornado-borne missiles determined by following the provisions of Section 4.3.

4.4.2.2 In designing the SSCs to withstand the design basis tornado winds, ASCE/SEI 7-10 criteria for designing SSCs for straight-line winds shall be used, except as specified here.

i) In calculating the design basis forces on SSCs corresponding to design basis tornado wind speeds, the ASCE/SEI 7-10 provisions shall be used based on applicable Exposure Category.

However, if no data on Exposure Category is available, Exposure Category C can be used regardless of the actual terrain roughness.

For these cases, the Velocity Pressure Exposure Coefficient (VPEC) can also be determined assuming Exposure Category C.

ii) For designing SSCs against tornado loads, the following load combinations shall be used for factored loads using strength design (note: ASCE/SEI 7-10 does not specify load combinations applicable for designing SSCs against tornado loads):

$D + F +\_0.8L + H + T_0 +R_0 +W_t$

where,

D = Dead Load, F = loads due to weight and pressure of fluids,L = Live Load, H = loads due to weight of pressure of soil, T_0 = loads caused by thermal effects, R_0 = piping and equipment loads and W_t = Tornado load, including APC and missile, as appropriate.

4.4.2.3 SSCs, or the barriers protecting safety-related SSCs, shall be designed to withstand the impact of site-specific tornado and hurricane missiles, as characterized in Table 4-1 of ANSI/ANS-2.3-2011.

i) WDC-3, WDC-4, and WDC-5 SSCs subjected to such missile impact shall be designed by calculating the capacity using ASCE/SEI 7-10 criteria for wind pressure loads, but appropriately considering the impaction nature of the load, including the deformation characteristics of the missiles.

ii) For designing barriers to protect such safety-related SSCs against tornado APC or tornado and hurricane missile impact loads, the permissible state of deformation of the barrier can be used to calculate the barrier capacity that may be more than the capacity calculated by using ASCE/SEI 7-10 criteria for wind pressure loads. For example, a concrete wall, acting as missile barrier to protect a fragile safety-related piece of equipment, can be permitted to deform beyond its yield limit. It may be possible to allow the occurrence of perforation or spalling if such does not adversely affect the safety function of the equipment that is being protected.

4.4.2.4 If a structure is not intentionally sealed to maintain an internal negative pressure for confinement of hazardous materials, and if openings greater than one square foot per 1000 cubic feet of volume are present, or if openings of this size can be caused by missile perforation, then the effects of internal pressure should be considered according to the applicable criteria in ASCE/SEI 7-10.

4.4.2.5 If a structure is sealed, then the APC associated with a tornado, as shown in Table 3.2-1 of ANSI/ANS-2.3-2011, shall be considered instead of internal pressures.

4.4.2.6 Since the maximum APC pressure occurs at the center of the tornado vortex where the wind speed is theoretically zero, a more severe loading condition occurs at the radius of maximum tornado wind speed, which is a finite distance from the vortex center. At the radius of maximum wind speed, the APC may be one-half its maximum value. Accordingly, a critical tornado load combination on a sealed building that shall be used is one-half maximum APC pressure combined with maximum tornado wind pressure.

4.4.2.7 A loading condition of APC alone can occur on the roof of a buried tank or sand filter, if the roof is exposed at the ground surface. Since APC pressure always acts outward, a rapid rate of pressure change, which can accompany a rapidly translating tornado, shall be analyzed to assure that it does not damage safety-related ventilation systems.

4.4.3 Fundamental SSC Design Guidelines for Wind Loads

The following seven fundamental principles shall be followed in developing a design to minimize the adverse consequences of all types of wind-related hazards. These are as follows:

a) Provide a continuous and traceable load path from surface to foundation;

b) Ensure that all viable loads and load combinations are accounted for;

c) Provide redundant structures that can redistribute loads when one structural element is overloaded;

d) Provide ductile elements and connections that can undergo deformations without sudden and catastrophic collapse;

e) Provide missile-resistant walls and roof elements;

f) Anchor mechanical equipment on roofs to resist specified wind and missile loads; and,

g) Minimize or eliminate the potential for windborne missiles.

4.4.4 Guidelines for Wind Hazard Evaluation of SSCs in Existing Facilities

The following guidelines below may be used for evaluating WDC-1 through WDC-5 SSCs in an existing facility:

a) The key to the evaluation of existing SSCs is to identify potential failure modes and to calculate the minimum wind speed that would cause the postulated failure. A critical failure mechanism could be the failure of the main wind-force resisting system of a structure, a breach of the structure envelope that allows release of toxic materials to the environment, or a breach that results in wind and water damage to the building contents.

b) The structural system of old existing facilities (i.e., 25 to 40 years old) may have considerable reserve strength because of conservatism used in the design, especially if the facility of the system was designed to resist abnormal effects. However, the facility could still fail to meet the requirements if the breach of the building envelope is not acceptable.

c) The weakest link in the load path of an SSC generally determines the adequacy or inadequacy of the performance of the SSC under all types of wind loads. Accordingly, the evaluation of existing SSCs should normally focus on the strengths of connections and anchorages and the ability of the wind loads to find a continuous path to the foundation or support system.

d) Experience from wind storm damage investigations provides the best guidelines for anticipating the potential performance of existing SSCs under wind loads. *Procedures for Predicting Wind Damage to Buildings* provides a methodology for estimating the performance of existing SSCs. The approach is directed primarily to structures, but can be adapted to systems and components as well. The methodology described in the previously mentioned procedure involves two levels of evaluation:

    i) Level I, essentially a screening process, should be performed before proceeding to Level II, which is a detailed evaluation.

    ii) The Level II process includes the following three steps:

        (a) Data collection;

        (b) Analysis of element failures; and,

        (c) Postulation of failure sequence.

4.4.4.1 Data Collection

a) Construction or fabrication of as-built drawings and specifications are needed to perform an evaluation of potential performance in extreme straight-line winds, tornado winds, and hurricane winds, and these should be obtained.

b) A site visit and walk down should be performed to verify that the SSCs are built according to written plans and specifications.

c) Modifications not shown on the drawings or physical deteriorations shall be noted.

d) Material properties are also required for the analyses, and an accurate determination of material properties could be the most challenging part of the evaluation process.

e) Median values of material properties shall be obtained, which will allow an estimate of the degree of conservatism in the design if other than median values were used in the original design.

4.4.4.2 Analysis of Element Failures

a) After determining the as-built condition and the material properties, various element failures of the SSCs shall be postulated. The nominal strength to just resist the assumed element failure shall be calculated.

b) Since the nominal strength is at least equal to the controlling load combination, the wind load to cause the postulated failure shall be calculated.

c) Once the wind load is known, the wind speed to produce the wind load shall be determined using the procedures of ASCE/SEI 7-10 and working backwards.

d) Wind speeds that cause all plausible failure modes shall be calculated and tabulated, and the weakest link determined from the tabulation of element failures.

e) These parameters shall then be used in the next step to determine the failure sequence.

4.4.4.3 Postulation of Failure Sequence

a) Failure caused by extreme winds is a progressive process, initiating with an element failure. Examples are failure of a roof-to-wall connection, inward or outward collapse of an overhead door, and window glass broken by flying roof gravel. Once the initial element failure occurs at the lowest calculated wind speed, the next event in the failure sequence shall be anticipated.

b) As an example, if a door fails, the internal pressure inside the building will increase causing larger outward acting pressures on the roof. The higher pressures could then lead to roof uplift creating a hole in the roof itself. With the door opening and roof hole, wind-driven air could rapidly circulate through the structure causing collapse of partition walls, damage to ceilings or ventilation systems, or transportation of small objects or debris in the form of windborne missiles. Each event in the sequence shall be associated with a wind speed.

c) All obvious damage sequences shall be examined for progressive failure.

4.4.4.4 Evaluation of Postulated Failures

a) If an SSC fails to meet the requirements applicable for the SSC and its WDC level, then the assumptions and methods of analyses shall be modified to eliminate some of the conservatism introduced in the evaluation methods.

b) The acceptable hazard probability levels can be raised slightly if the SSC comes close to meeting the requirements. Otherwise, various means of retrofit shall be examined.

c) Five options are listed for general guidance, but this list is not exhaustive and additional options may be considered, if necessary:

   i) Add x-bracing or shear walls to obtain additional lateral load-resisting capacity;

   ii) Modify connections in steel, timber or pre-stressed concrete construction to permit them to transfer momentum, thus increasing lateral load resistance in structural frames;

   iii) Brace a relatively weak structure against a more substantial one;

   iv) Install tension ties that run from roof to foundation to improve roof anchorage; and,

v) Provide x-bracing in the plane of a roof to improve diaphragm stiffness and thus achieve a better distribution of lateral load to rigid frames, braced frames or shear walls.

d) To prevent a breach of the structure envelope or to reduce the consequences of missile perforation, the following six general suggestions should be considered:

   i) Install additional fasteners to improve cladding anchorage;

   ii) Provide interior barriers around sensitive equipment or rooms containing toxic or hazardous materials;

   iii) Eliminate windows or cover them with missile-resistant grills;

   iv) Erect missile-resistant barriers in front of doors and windows;

   v) Replace ordinary overhead doors with heavy-duty doors that will resist the design wind loads and missile impacts; and,

   vi) Door tracks shall also be able to resist the wind loads.

e) Each SSC will likely have special situations that need attention. Personnel who are selected to evaluate existing facilities shall be knowledgeable of the safety-related function(s) and behavior of SSCs subjected to wind-related hazards.

5.0 Criteria and Guidelines for Flood, Seiche and Tsunami Design

This section provides guidance and criteria for design and evaluation of SSCs for mitigating flood hazards (i.e., flood seiche, tsunami). It provides guidance for:

a) Determining a Flood Design Category (FDC) of a SSC based on the severity of SSC failure consequence (Section 5.1);

b) Performing a site flood characterization and characterizing site hydrology and hydrological data (Section 5.2);

c) Determination of flood design parameters (Section 5.3);

d) Performing Probabilistic Flood Hazard Assessments (PFHAs) on the basis of which design parameters are related to the flood hazard (i.e., design basis flood level (DBFL)) (Section 5.4); and,

d) Designing SSCs to mitigate the effects of flood hazards (Section 5.5).

5.1 SSC Categorization for Flood Design

The design categorization process and criteria given in ANSI/ANS-2.26-2004 for seismic hazards shall also be used for flood design categorization as discussed below and as previously discussed in Section 2.

5.1.1 Flood design categorization shall be based on the severity of unmitigated failure consequences resulting from all precipitation-related and hydrology-related hazards (e.g., river flooding, dam failure, tsunami, landslide, etc.) applicable to the DOE site and facility. Precipitation-related hazards include both rainfall and snowfall.

5.1.2 The failure of safety function of some SSCs, when subjected to a flood-related hazard, can occur not only because of excessive deformation or distortion (e.g., for added hydrostatic or hydrodynamic water pressure), but also as a result of inundation of the SSC or intrusion of flood water into or onto the SSC. In selecting an SSC FDC and SSC design methods and criteria, such inundation and water intrusion-related failure modes (e.g., shorting or malfunctioning of an electric circuit or equipment) shall also be considered in determining unmitigated SSC failure consequences.

5.1.3 In addition to rupture, instability, deformation-related or distortion-related failure modes of the SSCs, potential failure modes resulting from flood water shall also be considered in determining unmitigated failure consequences.

5.1.4 Barriers, enclosures, dikes, and other SSCs, that are provided for flood protection of SSCs, with safety functions, shall be placed in a FDC equal to or higher than the category of the SSC to be protected.

5.1.5 These protective SSCs, or barriers, shall be designed using stress, strain, deformation limit, or leak tightness criteria appropriate for the protective function and the failure mode of the barrier. For example, if an enclosure is intended to protect an FDC-3 SSC from inundation, the enclosure shall be designed to ensure leak tightness which may or may not be accomplished simply by satisfying permissible stress criteria in ASCE/SEI 7-10, and additional testing or deformation criteria may need to be established to design the enclosure.

5.1.6 The site-specific flood hazard-related data collection and PHFA shall be based on the highest FDC category of the SSCs at the site.

5.1.7 The DBFL for a facility or a site shall be dependent on the highest category of the SSCs in the facility or at the site.

5.1.8 For a large site with varying topography, the DBFL may vary from facility to facility.

5.2 Site Characterization for Flood Design

5.2.1 General Requirements

The description of general requirements shall, at a minimum, include the following:

5.2.1.1 Precipitation, which includes rain and snow, and hydrologic characteristics of a site and its surroundings, shall be investigated in sufficient scope and detail to obtain the data necessary for performing a PFHA with a degree of rigor commensurate with the highest FDC applicable to any SSC in the site.

5.2.1.2 Site data and information are necessary for identifying and evaluating potential external accident initiators and for identifying and analyzing accident consequences external to the facility (see DOE-STD-3009).

5.2.1.3 The size of the region to be investigated and the type of data pertinent to the investigations shall be determined by the nature of the region surrounding the proposed or existing site.

5.2.1.4 Site characterization shall be carried out to obtain the data necessary for performing a site-specific PFHA, and design and evaluation of SSCs in accordance with this standard.

5.2.1.5 The site flood characterization shall be carried out by a review of the pertinent literature and field investigations, and shall follow the requirements given in the following sections.

5.2.1.6 The site flood characterization shall be performed by subject matter experts (SMEs) recognized in the industry and preferably having site-specific knowledge and experience. Data and other relevant information obtained from prior investigations shall be used, supplemented by additional investigations at the specific location as deemed necessary by the SMEs.

5.2.1.7 Guidelines and requirements for collecting flood-related hazard data that are necessary for conducting site-specific PFHA are provided in Subsections 5.2.2 and 5.2.3.

5.2.2 Site Characterization for Precipitation

Sites, for which no up-to-date site-specific PFHA has been performed in accordance with Section 5.3, shall develop monthly and annual summaries, including averages and periodical extremes, of precipitation and equivalent melted water contents at or near the site.

5.2.3 Characterization of Site Hydrology and Hydrological Data

5.2.3.1 For sites where no up-to-date site-specific PFHA has been performed in accordance with Section 5.3, a site flood characterization shall be performed in accordance with the guidelines and requirements given in Subsections 5.3.1 through 5.3.13.

5.2.3.2 Data provided in flood insurance studies by the Federal Emergency Management Agency (FEMA), and site-specific hydrological studies performed by DOE, including DOE-sponsored contractors, and other governmental agencies (e.g., U.S. Army Corps of Engineers (COE), U.S. Bureau of Reclamation, U.S. Geological Survey (USGS), Flood Insurance Administration (FIA), Department of Water Resources, Agricultural Department, NWS, Tennessee Valley Authority, etc.) may be used.

5.2.4 General Guidelines and Requirements for Hydrological Data Collection

5.2.4.1 Data on location, size, shape, and other hydrologic characteristics of streams, lakes, shore regions, and ground water environment influencing the site shall be collected.

5.2.4.2 A quantitative description of existing and planned water control structures that may influence the hydrologic conditions at the site shall be provided.

5.2.4.3 Hydrologic events that are potential sources of flooding for the site shall be determined. Hydrologic hazards listed in Table 5-1 shall be considered and their applicability of each hazard to the PFHA determined.

5.2.4.4 Hydrologic hazard data shall be collected to determine the flood sources and shall be used to evaluate potential flood-related hazards at the site.

5.2.4.5 Data collection processes may be iterative, as follows.

i) Initial data requirements shall focus on the need to identify potential sources of hydrologic flood-related hazards to the site.

ii) For each specific hydrologic flood-related hazard, a summary of hazard characteristics shall be provided.

iii) The worst case flood-related hazard shall be summarized, and only the worst case flood hazard needs to be summarized in detail.

iv) The flood-related hazard summary shall include the proximity of the potential source of flood hazard to the site and also include applicable reasons why certain data sources are unlikely or present negligible consequences to the site.

5.2.4.6 For applicable hydrologic hazards, additional data shall be required to perform a PFHA. Data sources shall include, but not be limited to:

i) Walk down of site and vicinity;

ii) Site-specific and regional topographic maps;

iii) Aerial photographs of the site and vicinity;

iv) Hydrologic data (i.e., stream gauge data);

v) Historical flood event reports;

vi) FEMA flood insurance studies; and,

vii) Dam-break studies.

5.2.4.7 Sources of available data shall include past site-specific hydrologic studies by DOE and DOE-sponsored contractors, studies performed by other government agencies (e.g., U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Geological Survey, Flood Insurance Administration, Department of Water Resources, Agricultural Department, National Weather Service, Tennessee Valley Authority, etc.), universities, and national laboratories.

5.2.4.8 Local and regional flood history with potential causes of flooding under extreme conditions shall be reported with date, level, peak discharge, and other relevant information.

5.2.4.9 New safety-related structures shall not be built on a floodplain unless flood mitigation measures are provided.

5.3 Determination of Flood Design Parameters for Flood-Related Hazards

Table 5-1 identifies 13 flood-related hazards and the natural and anthropomorphic phenomena causing them. The following 13 Subsections (Sections 5.3.1 through 5.3.13) provide guidance on the determination of flood design parameters for each flood-related hazard.

Table 5-1

Flood-Related Hazards

Flood-Related Hazard	**Natural and Anthropomorphic Phenomena**
River Flooding	Precipitation, rapid sedimentation, volcano-induced
Dam, Levee or Dike Failure	Earthquake, flood, static failure, upstream dam failure, landslide, volcano
Storm Surge	Hurricane
Tsunami	Earthquake
Seiche	Earthquake, wind
Wave	Tsunami, wind,
Landslide	Precipitation, volcano
Volcano-Created Flood	Volcano
Flood Runoff	Precipitation, ponding, inadequate drainage capacity
Change in Ground Water Level	Precipitation, ponding, flooding, drought and over pumping
Mudflow	Volcano, earthquake, precipitation
Water Borne Debris	Damage to upstream objects or landscape that produce debris
Subsidence-Induced Flooding	Supercritical Fluid Extraction (SFE)

5.3.1 River Flooding

5.3.1.1 Each river in the regional area of the site that could impact the site shall be identified and characterized with respect to its location and elevation relative to the site and its facilities.

5.3.1.2 The boundaries of the region to be investigated for river flooding hazard depends primarily on whether the rivers could cause floods large enough under extreme conditions to contribute to flooding at the site. Regional investigations shall be conducted for rivers relatively close to the site (i.e., rivers with flood plain boundaries less than a few kilometers from the site).

5.3.1.3 For rivers that could be potential sources of site flooding, the potential for flooding shall be characterized by collecting the following information:

- i) Location and elevation of the rivers at the location nearest the site;
- ii) Historical records of stream flow data (i.e., maximum yearly peak discharge and stage elevation) with recording location;
- iii) Maximum flood level that may be expected from a combination of the most critical historical meteorological and hydrologic conditions;
- iv) Characterization of geometric and hydraulic properties of the channel closest to the site. The geometric properties of the channel include Manning's roughness coefficient and top-width elevation tables for cross sections, and streambed slope; and,
- v) Presence of bridges or natural river flow constrictions that could cause flooding due to ice or debris jams.

5.3.1.4 For rivers for which no peak discharge records are available, the following information shall be gathered:

- i) Characteristics of the watershed basins of the river; and,
- ii) Properties of the drainage basins including topographic maps of the basin and land cover maps.

5.3.2 Dam, Levee, or Dike Failure

5.3.2.1 Historical experiences and analytical studies indicate that floods associated with a dam break can significantly exceed flood levels that occur due to natural events. All dams upstream on rivers in the regional area of the site shall be identified and the following characteristics summarized:

- i) Name of dam;
- ii) Owner of dam;
- iii) Type of dam (e.g., earth fill, concrete, etc.);
- iv) Date of dam completion;
- v) River name and location (e.g., river mile);
- vi) Total height of dam;
- vii) Capacity of dam; and,
- viii) Closest distance from the river to the site.

5.3.2.2 For dams that could pose a threat to the site, should they fail, a detailed collection of data shall be conducted.

5.3.2.3 Failures of dams that could pose a hydrologic hazard to the site include dams close enough to the site with a relatively large storage capacity or distant dams with a large storage capacity. The collection of data shall include existing dam break studies or data necessary to perform dam break analyses.

5.3.2.4 For dams for which dam break studies have been conducted as part of dam safety emergency management planning evaluations, results of these studies shall be collected, including date of study, dam failure scenario (e.g., flood, earthquake, static failure due to internal erosion), peak discharge and elevation at closest point from the site.

5.3.2.5 For dams for which no dam break studies are available, or for which dam break studies are unavailable for all the potential hazards (e.g., seismic, flood, landslide, upstream dam failure), data shall be collected to conduct such studies.

5.3.2.6 Data to be collected include that which is necessary to perform a river flooding hazard analysis of the river reach upstream of the dam(s), seismic hazard analysis, potential landslide hazard analysis of the embankment or the dam itself, and dam break analysis. These data include:

i) Results of seismic hazard analysis;

ii) Data necessary to perform upstream river flooding hazard analysis;

iii) Data on dam and dam characteristics necessary to evaluate its resistance to the seismic loads and overtopping. These data include;

  (a) Material properties of the dam and abutment; and,

  (b) Characteristics of gates and other mechanical equipment which could affect the dam performance.

iv) Reservoir depth, length and storage elevation tables;

v) Manning's roughness coefficient, and top-width elevation tables for downstream cross sections;

vi) In the case of overtopping events, the depth of overtopping at which failure occurs;

vii) In the case of hydrologic events, an inflow hydrograph; and,

viii) Outflow characteristics for emergency spillway, outlets, and turbines.

5.3.3 Storm Surge

5.3.3.1 For sites located within regions that experience hurricanes or strong storm squalls and which are located nearby large bodies of water, data on surges associated with such storms shall be collected from available flood hazard analyses.

5.3.3.2 For cases where no such data are available, data necessary to perform a joint probability hurricane frequency hazard analysis shall be collected along with data on:

i) Bathymetric characteristics of the coastline (i.e., depth tables);

ii) Tide levels; and.

iii) Local topographic data between the site and large bodies of water.

5.3.4 Tsunami

5.3.4.1 Tsunamis are ocean waves generated by vertical sea-floor displacements associated with large offshore earthquakes. Such earthquakes may be those occurring close to a site or at great distances from a site.

5.3.4.2 For sites located near an ocean, seismic data shall be collected to assess the potential for off-shore earthquakes which could create a tsunami.

5.3.4.3 Data collected shall include historical records of tsunami occurrence in the site region.

5.3.4.4 Should the potential for a tsunami exist, local topographic data between the site and the ocean shall be collected and evaluated.

5.3.4.5 Paleontological data should be collected for sites containing facilities with SSCs in FDC-4 or FDC-5 where no historical records of tsunamis are available at the site.

5.3.5 Seiche

5.3.5.1 Seiches are undulations of the surface of a body of water such as a bay, lake, or reservoir, set up by interaction of the water body with seismic forces, and winds.

5.3.5.2 For sites located near large bodies of water, seismic and meteorological data shall be collected to assess the potential of creating seiche effects. See Section 4.2.3 for guidance on meteorological data collection.

5.3.5.3 Should the potential for a seiche exist, local topographic data between the site and large bodies of water shall be collected and evaluated.

5.3.6 Wave

5.3.6.1 For sites located near bodies of water and in regions exposed to extreme winds, meteorological data shall be evaluated to assess the wave action. See Section 4.2.3 for guidance on meteorological data collection.

5.3.6.2 Should the potential for a wave hazard exist, water depths, fetch characteristics, and local topographic data between the site and large bodies of water shall be collected and evaluated.

5.3.7 Landslide

5.3.7.1 Land sliding into a river can dam the river and pose a flooding hazard upstream within the impoundment area or downstream in the event of overtopping of the dam.

5.3.7.2 Tectonic uplift can have a similar damming effect.

5.3.7.3 Should the potential for a landslide hazard exist, relevant information associated with this phenomenon shall be collected and evaluated.

5.3.8 Volcano-Created Flood

5.3.8.1 Volcanic eruption debris can create natural dams in narrow valleys which can lead to potential flood hazards resulting from a volcano-created flood.

5.3.8.2 A volcanic eruption can also cause mudflows (See Section 5.3.11), rapid sedimentation in river, and rapid snowmelt, to create potential flood hazards. The stability of slopes whose failures may cause this hazard shall be investigated.

5.3.8.3 For DOE sites in regions with potential volcanic activity (e.g., Idaho, Washington), topographic data shall be collected to indicate the most likely locations of valley damming which could impact the site. See Section 8.0 with respect to volcano hazards.

5.3.9 Flood Runoff

5.3.9.1 Intense precipitation or snow melt may create local ponding or overland flooding when the soil infiltration capacity is exceeded. In addition, drainage capacity may be exceeded creating additional flooding.

5.3.9.2 Local topographic characteristics of drainage areas including depressions, terrain slope, nature of soil vegetation or Manning's coefficients, and soil infiltration indices shall be collected.

5.3.9.3 Precipitation and snowfall data shall be collected. See Section 4.2.3 for guidance on meteorological data collection.

5.3.10 Change in Ground Water Level

5.3.10.1 Intense precipitation or snow melt and infiltration can cause ground water to rise and eventually flood sites.

5.3.10.2Over pumping, reduced recharge and droughts can cause significant declines in ground water levels. This can lead to land subsidence and well failure.

5.3.10.3 For sites that use ground water for production, cooling, or human consumption, or that may be subject to land subsidence, records shall be kept of ground water level trends on a quarterly basis.

5.3.10.4 The water-level data shall be adequate to document any long-term safety or environmental effects of ground water withdrawal.

5.3.10.5 For sites with shallow ground water tables, data on regional and local aquifers and aquitards shall be collected, including formations and sources of the aquifers, local well log records, and drainage capacity.

5.3.11 Mudflow

5.3.11.1 A mudflow is a rapid and fluid type of downhill mass wasting; a rapid movement of a large mass of mud formed from loose soil and water. Mudflows can also result from lahar and pyroclastic flows associated with volcanic eruptions (see Section 5.3.8 and Section 8).

5.3.11.2 For sites located in areas where mudflows are possible (e.g., in valleys) relevant information associated with this phenomenon shall be collected and evaluated.

5.3.12 Water Borne Debris

5.3.12.1 Water borne debris can occur from tsunamis and other phenomena that occur upstream of a site, causing damage from the force of the debris on the SSCs.

5.3.12.2 For sites located in areas where damage from waterborne debris is possible (e.g., coastal, harbor, estuarine areas) relevant information associated with this phenomenon shall be collected and evaluated.

5.3.13 Subsidence-Induced Flooding

5.3.13.1 Subsidence-induced flooding can result from anthropomorphic SFE activities (i.e., process of separating one component (i.e., the extractant) from another (i.e., the matrix) using supercritical fluids as the extracting solvent.

5.3.13.2 For sites located in areas where damage from subsidence-induced flooding from SFE activities is possible (e.g., Sacramento Valley, Gulf Coast) relevant information associated with this phenomenon shall be collected and evaluated.

5.4 Probabilistic Flood Hazard Assessment and Determination of Flood Design Parameters

5.4.1 General Requirements

5.4.1.1 For sites and facilities with FDC-3, FDC-4, and FDC-5 SSCs, the results of the PFHA for a given credible flooding source shall be presented in the form of a flood-related hazard curve showing the relationship between flood level and the design basis return period in years. The DBFL for a given SSC shall be the highest flood level considering all the credible flooding sources for the site corresponding to the design basis return period applicable for the FDC of the SSC.

5.4.1.2 For sites and facilities with only FDC-1 and FDC-2 SSCs, the DBFL shall be determined either on the basis of the requirements in IBC and ASCE/SEI 7-10, or following the applicable provisions of this standard. However, the DBFL shall not be lower than that determined on the basis of IBC and ASCE/SEI 7-10 requirements.

5.4.1.3 Return periods for the design basis flood for various flood design categories of SSCs shall be as provided in Table 5-2.

5.4.1.4 For sites and facilities with FDC-3, FDC-4, and FDC-5 SSCs, a site-specific PFHA shall be performed to develop a flood-related hazard curve to establish the DBFL. Guidelines and criteria for such PFHAs are provided in Section 5.4.2.

5.4.1.5 Guidelines and criteria for establishing a DBFL for facilities with only FDC-1 and FDC-2 SSCs are provided in the Section 5.4.3.

Table 5-2

Return Period (Years) for Design Basis Flood for Various Flood Design Categories

SSC Category	FDC-1	FDC-2	FDC-3	FDC-4	FDC-5
Return Period (Years)	500	2000	10,000	25,000	100,000

5.4.2 Determination of DBFL for Facilities with FDC-3, FDC-4, and FDC-5 SSCs

a) For sites and facilities with FDC-3, FDC-4, and FDC-5 SSCs, a site-specific PFHA shall involve the following two steps:

  i) Perform a Flood Screening Analysis (FSA) to evaluate the magnitude of flood hazards that may impact the SSCs under consideration. Guidelines and criteria for a FSA are provided in Section 5.4.2.1.

  ii) Perform a Comprehensive Flood Hazard Assessment (CFHA), if required, based on the results and conclusions of the FSA. Guidelines and criteria for a CFHA are provided in Section 5.4.2.2.

5.4.2.1 Flood Screening Analysis

a) The objective of a FSA is to determine if a CFHA would be necessary for the site by conducting a preliminary PFHA. The FSA shall include the following steps:

  i) Collect and compile site-specific flood-related hazard related data, identify the potential sources of flooding, if any, and perform a site characterization study following the guidelines and criteria given in Section 5.2.

  ii) The potential sources of flooding to be considered shall include, but not limited to, the following:

    (a) River/stream flooding;

    (b) Dam, dike, or levee failure;

    (c) Local precipitation (i.e., rainfall and snow melt); and,

    (d) Storm surge, seiche, and tsunami.

  iii) If the return period for a potential flood source is larger than the design basis return period applicable for the FDC in Table 5-2, the source does not need to be considered.

  iv) Determine whether the site can be considered a flood-dry site (i.e., whether the facility SSCs in the site can be considered physically removed from the potential sources of flooding so that the safety functions of the SSCs are clearly and obviously unaffected by hazards from any of the potential flooding sources).

  v) The flood dry-site determination shall be performed by a panel of experts consisting of both flood hazards SMEs and safety evaluation SMEs.

  vi) For sites that cannot be clearly demonstrated to be a flood-dry site, perform a preliminary PFHA following the guidelines given in Appendix D, and determine if a CFHA is necessary.

5.4.2.2 Comprehensive Flood Hazard Assessment (CFHA)

a) When the results of the FSA and preliminary PHFA conclude that a CFHA is a necessary evaluation to be conducted for the site, the CFHA shall be performed.

b) Additional guidance for conducting a FHA is provided in Appendix D.

c) The CFHA shall be performed probabilistically considering and propagating the uncertainties in the parameters used to estimate the DBFL.

d) A CFHA shall consider meteorological, hydrologic and hydraulic assessments of the potential sources of flood hazards identified in the FSA and the reliability of flood protection systems (e.g., dams, levees), if present.

e) If applicable, the CFHA considerations shall include the following:

  i) Estimation of rainfall and snowfall frequency in watersheds;

  ii) Overland flow assessment due to precipitation;

  iii) Hydrologic modeling of watershed responses using verified and validated models;

  iv) Assessment of discharge (i.e., flow rates) and flood elevations using detailed hydraulic modeling techniques;

  v) Estimation of joint natural hazard events frequency (e.g., joint probability analysis shall be performed to assess surge level frequencies;

  vi) Assessment of likelihood of upstream dams and levees failure where all causes of dam failure shall be accounted for; and,

  vii) Assessment of the uncertainty due to the limited data for estimating model parameters, the modeling of physical processes, and the interpretation of the available data.

f) A full-scope probabilistic approach to model river flooding shall include temporal and spatial frequency estimates of the random meteorological parameters that contribute to precipitation and runoff and an estimate of the modeling uncertainty of the watersheds.

g) Three acceptable approaches are available to evaluate the frequency of extreme flows and/or levels due to hydrologic events, as follows:

  i) Stochastic methods;

  ii) Probabilistic hydrologic modeling (e.g., Bayesian analysis, joint probability methods, etc.); and,

  iii) Paleohydrological analysis (i.e., evaluating ancient evidence using age-dating techniques to deduce early extreme hydrologic events).

h) Causes of dam failure to be evaluated include:

  i) Hydrologic, seismic, hydrostatic, operations-related error;

  ii) Random structural failure;

  iii) Upstream dams; and,

  iv) Landslides.

i) Dam failure-induced flood levels shall be determined by analyses using validated dam break models.

j) Uncertainty for the dam break model analysis parameters (e.g., breach size, time to failure, flood time arrival) shall be accounted for in the analysis.

k) A simplified dam failure analysis is acceptable if the analysis accounts for uncertainty.

l) To ensure that the DBFL determined from a CFHA conservatively accounts for a recurrence of the event causing the flooding, a review of the data on historical floods that may have affected the site shall be performed.

m) Since the hydraulic characteristics of the basin could have changed since the maximum historical flood, the flood level itself may not be able to form a direct comparison to the DBFL. Accordingly, the amount of water produced, or the rainfall intensity and distribution, shall be compared to the event leading to the DBFL.

n) For FDC 3, FDC-4, and FDC-5 SSCs, the DBFL event shall be equal to or greater than the maximum historical event in the basin.

5.4.3 Determination of DBFL for Facilities with FDC-1 and FDC-2 SSCs

5.4.3.1 For FDC-1 and FDC-2 SSCs at a site for which a site-specific CFHA has been performed, the DBFL shall be determined using the site-specific flood-related hazard curve.

5.4.3.2 The DBFL shall not be lower than that estimated by utilizing existing flood insurance studies applicable to the site.

5.4.3.3 For FDC-2 SSCs at a site for which no site-specific CFHA has been performed, the DBFL shall be determined based on a FSA following the steps described in Section 5.4.2.1, and recognizing that the DBFL shall correspond to a return period of 1,000 years.

5.4.3.4 For FDC-1 SSCs at a site for which no site-specific CFHA has been performed, the DBFL shall be determined utilizing existing flood insurance studies applicable to the site, but recognizing that the DBFL shall correspond to a return period of 500 years.

5.4.4 Flood Event Combinations

5.4.4.1 For each potential flood source, the determination of DBFL shall consider several event combination cases as follows:

i) River Flooding

  (a) Case 1: Peak flood elevation due to all flooding contributors with the exception of upstream dam failure.

  (b) Case 2: Wind-waves corresponding to winds acting in the most favorable direction and Case 1. The wind shall be determined from a probabilistic analysis that considers the joint occurrence of river flooding and wind generated waves and as a minimum corresponds to the 2-year wind speed.

  (c) Case 3: Ice or debris forces (i.e., static, dynamic) and Case 1.

  (d) Case 4: Peak and ground water level and Case 1.

ii) Levee/Dam Failure

    (a) Case 1: Peak flood elevation due to all modes of failure (i.e., overtopping, seismically or landslide induced, random structural failure, upstream dam failure, debris or ice dam failure).

    (b) Case 2: Wind-waves corresponding to winds acting in the most favorable direction and Case 1. The wind shall be determined from a probabilistic analysis that considers the joint occurrence of dam failure and wind-generated waves and as a minimum correspond to the 2-year wind.

iii) Storm Surge/Seiche

    (a) Case 1: Peak flood levels plus mean high tide levels.

    (b) Case 2: Surge-associated waves and Case 1.

iv) Tsunami

    (a) Tsunami-tide effects corresponding to the mean high tide level.

v) Local Precipitation

    (a) Case 1: Peak flood based on runoff analysis due to rain/snow melting.

    (b) Case 2: Surge-associated waves and Case 1.

    (c) Case 3: Ponding on the roof.

    (d) Case 4: Peak ground water level and Case 1.

5.4.4.2 The combination of the potential flood sources shall be assumed to be perfectly correlated for the purpose of developing flood hazard curves.

5.5 SSC Design and Evaluation to Mitigate Flood-Related Hazards

5.5.1 General Flood Design Overview

5.5.1.1 This section presents the design guidelines and criteria for mitigating the flood-related hazards that are identified, characterized, and assessed in Sections 5.3 and 5.4; and also presents alternative design strategies for mitigating flood hazards.

5.5.1.2 Guidance is also provided to evaluate SSCs in existing facilities that may not be located above the DBFL determined in accordance with the provisions in Section 5.4.

5.5.1.3 Table 5-3 summarizes the flood mitigation criteria for FDC-1 through FDC-5. The criteria are specified in terms of the flood hazard input, hazard annual probability, which is defined simplistically as the inverse of return period for the design basis flood event, SSC design requirements, and basic emergency operation plan requirements.

5.5.1.4 The hazard annual probability levels in Table 5-2 correspond to the mean hazard.

5.5.1.5 Evaluation of the flood design basis for SSCs consists of the following determinations and evaluations:

i) Determination of the DBFL for each flood-related hazard as defined by the hazard annual probability of exceedance and applicable combinations of flood hazards;

ii) Evaluation of the site storm water management system (e.g., site runoff and drainage, roof drainage);

iii) Development of a flood design strategy for the DBFL that satisfies the design requirements (e.g., build above the DBFL, harden the facility); and,

iv) Design of civil engineering systems (e.g., buildings, buried structures, site drainage, retaining walls, dike slopes) to the applicable DBFL and design requirements.

5.5.1.6 Each of these areas is briefly described in the Subsections 5.5.2 through 5.5.7.

Table 5-3

Summary of Flood Mitigation Criteria

Item	**Flood Design Category**				
	FDC-1	**FDC-2**	**FDC-3**	**FDC-4**	**FDC-5**
Flood Hazard Input	Flood insurance studies or equivalent input based on Sections 5.2 and 5.3, including the combinations in Table 5-4	Flood insurance studies or equivalent input based on Sections 5.2 and 5.3, including the combinations in Table 5-4	Site probabilistic hazard analysis based on Sections 5.2 and 5.3, including the combinations in Table 5-4	Site probabilistic hazard analysis based on Sections 5.2 and 5.3, including the combinations in Table 5-4	Site probabilistic hazard analysis based on Sections 4 and 5, including the combinations in Table 5-4
Mean Hazard Annual Probability (Return Period)	$<2x10^{-3}$ (500 year)	$<5x10^{-4}$ (2000 year)	$<1x10^{-4}$ (10,000 year)	$<4x10^{-5}$ (25,000 year)	$<1x10^{-5}$ (100,000 year)
SSC Design Requirements	(a) For SSCs with structural failure modes: Applicable criteria (e.g., applicable local regulations, and ASCE/SEI 7-10) shall be used for building design for flood loads (i.e., load factors, design allowables), roof design and site drainage, except that, since the design basis return periods have been selected here to directly account for the levels of risks associated with the SSC failure, a constant Dynamic Pressure Coefficient, C_p of 2.8 shall be used for all SSCs instead of the Risk Category dependent values given in Table 5.4-1 of ASCE/SEI 7-10, recognizing that, in ASCE/SEI 7-10, C_p values are used as a proxy to account for the risk variations among the various Risk Categories of ASCE/SEI 7-10 (b) The design of flood mitigation systems (i.e., levees, dams, etc.) shall comply with applicable standards as referred to in these criteria. (c) For SSCs with inundation failure modes: SSCs shall be either placed above DBFL or shall be protected from inundation by barrier structures designed meeting the requirements (a) above				
Emergency Operations Plans	Required to evacuate on-site personnel if life safety is impacted by the DBFL	Required to evacuate on-site personnel if life safety is impacted by the DBFL	Required to evacuate on-site personnel if life safety is impacted by the DBFL ,and to secure vulnerable areas if site is impacted by the DBFL	Required to evacuate on-site personnel not involved in essential operations if life safety is impacted by the DBFL. Provide for an extended stay for personnel who remain. Procedures shall be established to secure the facility during the flood such that operations may continue following the event.	

5.5.2 Design Basis Flood Level (DBFL)

5.5.2.1 As part of the PFHA that is performed for a site, the sources of flooding (e.g., rivers, lakes, local precipitation) and the individual flood hazards (e.g., hydrostatic forces, ice pressure, hydrodynamic loads) shall be identified.

5.5.2.2 A site or individual SSC may be impacted by multiple sources of flooding and flood hazards (e.g., many sites shall have to consider the hazards associated with river flooding).

5.5.2.3 All sites shall design a storm water management system to handle the runoff due to local (i.e., on-site or near site) precipitation.

5.5.2.4 Events that contribute to the potential for river flooding (i.e., spring snowmelt, upstream-dam failure, etc.) shall be considered as part of a PFHA. Accordingly, at a site there may be multiple DBFLs that shall be considered.

5.5.2.5 For sites with the potential for river flooding, a DBFL shall be determined for river flooding and for local precipitation which determines the design of the site storm water management systems.

5.5.2.6 For sites located on rivers or streams, the meteorological and hydrologic events that produce intense local precipitation are often distinct from those which produce high river flows. In this instance, various aspects of the design for a SSC shall be determined by different flood hazards. As a result, the term DBFL is used in a general sense that applies to the multiple flood hazards that may be included in the design basis.

5.5.2.7 The DBFL for a SSC for a flood hazard (e.g., river flooding, local precipitation) is defined in terms of:

i) Peak-hazard level (e.g., flow rate, depth of water) corresponding to the mean hazard annual probability as shown in Table 5-3, including the combination of flood hazards (e.g., river flooding and wind-wave action) provided in Table 5-4; and,

ii) Corresponding loads associated with the DBFL peak-hazard level and applicable load combinations (e.g., hydrostatic and/or hydrodynamic forces, debris loads).

5.5.2.8 The first consideration shall be determined as part of the PFHA. Limited FHAs for some DOE sites have been conducted and flood loads have been assessed for the DBFL on an SSC-by-SSC basis.

5.5.2.9 Table 5-4 defines the flood design basis events that shall be considered. The events listed in Table 5-4 should be considered as part of the site PFHA (i.e., if a river is a source of flooding, wind waves shall be considered).

5.5.2.10The DBFL is determined by entering the flood-related hazard curve that includes the combination of events provided in Table 5-4 (e.g., at a site located on an ocean shore, the flood-related hazard curve shall include the effects of storm surge, tides and wind-waves.

Table 5-4

Design Basis Flood Events

Primary Hazard	Case No.	Event Combinations*
River flooding	1	Peak flood elevation. Note: The hazard analysis for river flooding should include all contributors to flooding, including releases from upstream dams, ice jams, etc. Flooding associated with upstream-dam failure is included in the dam failure category.
	2	Wind-waves corresponding, as a minimum to the 2-year wind acting in the most favorable direction coincident with the peak flood or as determined in a probabilistic analysis that considers the joint occurrence of river flooding and wind generated waves.
	3	Ice forces and Case 1.
	4	Evaluate the potential for erosion, debris, etc. due to the primary hazard.
Dam failure	1	All modes of dam failure shall be considered (i.e., overtopping, seismically induced failure, random structural failures, upstream dam failure, etc.)
	2	Wind-waves corresponding, as a minimum to the 2 year wind acting in the most favorable direction, coincident with the peak flood or as determined in a probabilistic analysis that considers the joint occurrence of river flooding and wind generated waves.
	3	Evaluate the potential for erosion, debris, etc. due to the primary hazard.
Local precipitation	1	Flooding based on the site runoff analysis shall be used to evaluate the site drainage system and flood loads on individual facilities.
	2	Ponding on the roof to a maximum depth corresponding to the level of the secondary drainage system.
	3	Rain and snow, as specified in applicable regulations.
Storm surge, seiche (due to hurricane, seiche, squall lines, etc.)	1	Tide effects corresponding to the mean high tide above the MLW** level (if not included in the hazard analysis).
	2	Wave action and Case 1. Wave action should include static and dynamic effects and potential for erosion.

Levee or dike failure	1	Should be evaluated as part of the hazard analysis if overtopping and/or failure occur.
Snow	1	Snow and drift roof loads as specified in applicable regulations.
Tsunami	1	Tide effects corresponding to the mean high tide above the MLW** level (if not included in the hazard analysis).

* Events are added to the flood level produced by the primary hazard.

** MLW-Mean Low Water.

5.5.3 Flood Evaluation Process

5.5.3.1 The following describes the steps involved in the evaluation of SSCs. The procedure is general and applies to new and existing facilities and it is oriented toward the evaluation of individual SSCs.

5.5.3.2 Due to the nature of flood events (i.e., river flooding may inundate a large part of a site and thus many SSCs simultaneously), it may be possible to perform an evaluation for the entire site or a group of SSCs.

5.5.3.3 The flood evaluation process is illustrated in Figure 5-1. It is divided into the consideration of regional flood hazards and local precipitation.

5.5.3.4 For new construction, the design practice is to construct the SSC above the DBFL, thus avoiding the flood hazard and eliminating the consideration of flood loads as part of the design.

5.5.3.5 The design of the site storm water management system and structural systems (i.e., roofs) for local precipitation shall be adequate to prevent flooding that may damage a SSC or interrupt operations.

5.5.3.6 To perform the flood evaluation for a SSC, the results of a flood screening analysis or a PFHA shall be available. The steps in the flood-related hazard evaluation process include the following:

i) Determine the SSC FDC;

ii) Determine the DBFL for each type or source of flooding;

iii) Assess the flood loads (e.g., hydrostatic and hydrodynamic loads) or other effects (e.g., scour, erosion) on a SSC-by-SSC basis;

iv) For a new facility, locate the SSCs that may malfunction if submerged above the DBFL, if possible. If this cannot be done, proceed to the next step;

v) Develop a design strategy to mitigate flood hazards that impact the SSC. Options include hardening the SSC, modifying the flood path, and developing emergency operation plans to provide for occupant safety and to secure vulnerable areas.

vi) If the SSC is located below the DBFL level even if the SSC has been hardened, emergency procedures shall be provided to evacuate personnel if life safety is in danger and to secure the SSC prior to the arrival of the flood;

vii) Develop an initial site-drainage system and roof-system drainage plan and structural design per applicable regulations. Typical storm water management systems are designed for not less than the 25-year, 6-hour storm. The minimum storm sewer size is typically 12 inches and the minimum culvert size is 15 inches. For roof drain systems, the minimum pipe size for laterals and collectors are typically 4 inches. Storm water management systems usually have sufficient capacity to ensure that runoff from the 100-year, 6-hour design storm will not exceed a depth of 0.87-foot at any point within the street right-of-way or extend more than 0.2-foot above the top of the curb in urban streets;

viii) Perform a hydrologic analysis for the site to evaluate the performance of the site storm water management system considering roof drainage, anthropomorphic, and natural watercourses for the DBFL local precipitation for each SSC;

ix) The site analysis shall determine the level of flooding, if any, at each SSC. Guidelines for performing a hydrologic analysis are located in Section 5.2.3;

x) For SSCs where flooding occurs, assess whether the SSC performance is satisfactory.

xi) If the SSC performance is unsatisfactory, a modification of the site storm water management system shall be required. Due to the different DBFLs for different FDC SSCs, this step shall be performed for a number of flood events.

xii) Evaluate the drainage and structural design of roof systems for the DBFL local precipitation. The structural design of the roof system shall satisfy design criteria for loads due to ponding that result from clogged/blocked drains and snow and ice loads. These were either developed during the design of existing facilities or shall be those from applicable regulations.

xiii) If the design criteria for the roof are exceeded (i.e., deflection, stress allowables), the design shall be revised.

xiv) If the DBFL for a SSC due to local precipitation produces unacceptable levels of flooding, design modifications shall be developed. The design modifications shall provide for additional capacity (i.e., runoff capacity, additional strength) to mitigate the damage level. Alternative design strategies are discussed in Section 5.3.

xv) For SSCs that are impacted by the DBFL, emergency operation plans shall be developed to provide for the life safety of personnel and to secure critical areas.

5.5.3.7 In principle, each SSC shall be designed in accordance with the requirements for the applicable FDC. However, because floods have a common-cause impact on SSCs that are in proximity to one another, the design basis for the most critical SSC may govern the design for other SSCs or for the entire site. Accordingly, it may be more realistic economically and functionally to develop a design strategy that protects the most critical SSC and simultaneously that of other SSCs (i.e., it may be feasible to harden a site (e.g., construct a levee system), thus protecting all SSCs).

5.5.3.8 Conversely, it may be impractical to develop a design strategy that protects the entire site when SSC locations vary substantially (i.e., they are at significantly different elevations or there are large spatial separations).

5.5.3.9 The possible structural or functional interaction between SSCs shall be considered as part of the evaluation process. For example, if an SDC-5 SSC requires emergency electric power to protect the SSC, structures that house emergency generators and fuel shall be designed to the DBFL for FDC-5 SSC.

5.5.3.10In general, a systematic review of a site for possible structural or functional dependencies is required. As an aid to the review, the analyst can develop a logic model that displays the functional and structural dependencies between SSCs.

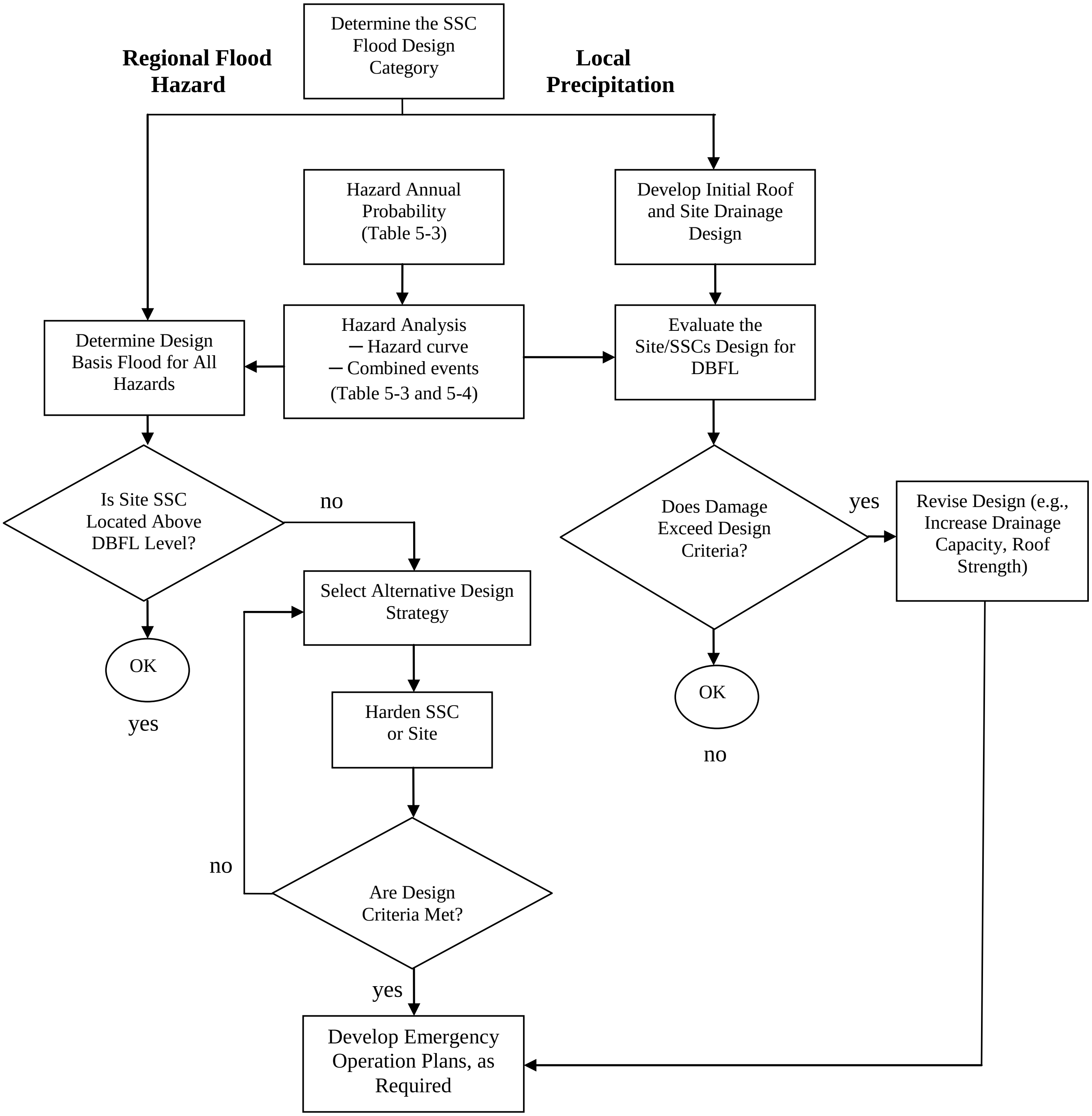

Figure 5-1 Flood Evaluation Process

5.5.4 Flood Design Strategies

5.5.4.1 The basic design strategy for SSCs in FDC-2 to FDC-5, excluding local precipitation, is to construct the SSC above the DBFL. When this can be done, flood hazards do not have to be considered in the design basis except that possible raised ground water level shall be considered. The flood criteria have been established with this basic strategy in mind.

5.5.4.2 Note that local precipitation is an exception since all sites shall consider this hazard in the design of the site stormwater management system, roof systems, etc.

5.5.4.3 Since it may not always be possible to construct a new SSC above the DBFL level, alternate design strategies shall be considered. The following lists the hierarchy of flood design strategies:

i) Situate the SSC above the DBFL level;

ii) Reduce the design basis flood hazard; or,

iii) Harden the site or SSC to mitigate the effects of the DBFL such that the SSC is protected; and,

iv) Establish emergency operation plans to safely evacuate employees and secure areas with hazardous, mission-dependent, or valuable materials.

5.5.4.4 If an SSC is situated above the DBFL, its protection is readily satisfied.

5.5.4.5 If an SSC is located below the DBFL, alternatives should be considered to modify the magnitude of the flood or mitigate its effects such that the likelihood of damage and interruption of operations is acceptably low.

5.5.4.6 Emergency operation plans shall be developed that establish the procedures to be followed to recognize/identify the flood hazard in a timely manner and provide for occupant safety and secure areas that may be vulnerable to the effects of flooding. While the implementation of emergency operation plans is necessary to provide for occupant safety, they generally do not adequately limit the level of damage and interruption to facility operations.

5.5.4.7 Under certain circumstances the hazard that results from the design basis flood can be modified to limit the magnitude of the hazard. Alternatives include the construction of detention ponds that provide for the collection and controlled release of runoff onsite, modification of stream channels, etc.

5.5.4.8 The strategy of hardening an SSC and providing emergency operation plans is secondary to siting facilities above the DBFL level since some probability of damage does exist and SSC operations may be interrupted. If it is determined that a SSC may be impacted by the DBFL and thus shall be hardened, the designer shall determine the flood loads associated with the DBFL.

5.5.4.9 The design of flood mitigation systems (i.e., exterior walls, flood-proof doors, etc.) shall be conducted in accordance with the requirements specified in applicable regulations.

5.5.4.10 The evaluation of the site storm water management system and roof design (i.e., drainage and structural capacity) differs somewhat from that for other flood hazards.

i) All sites shall be designed for the effects of local precipitation; and,

ii) The adequacy of the site storm water management system is measured in terms of the impact of local flooding on SSCs at the site. For example, the initial design of the site storm water management system may correspond to the 25-year rainfall 6-hour storm.

5.5.4.11 Should the DBFL for a SSC correspond to a 5 x 10^{-4} per year rainfall, the site storm water management system design clearly does not meet the above criterion. However, at this point the only conclusion that can be reached is that the system (i.e., storm sewers, etc.) will be filled to capacity.

5.5.4.12 The actual impact of the DBFL precipitation on the SSC shall be assessed by conducting a hydrologic evaluation for the site that accounts for natural and anthropomorphic watercourses on site, roof drainage, etc. The analysis may conclude that flooding is limited to streets and parking lots. If temporary flooding in these areas does not significantly affect the operation and safety of the SSC, then it may be concluded that the design of the site-drainage system (i.e., for the 25-year rainfall) is adequate.

5.5.4.13 Conversely, if flooding does result in significant damage that impairs the operation or safety of SSCs, appropriate measures shall be taken to ensure the safety function of the SSC. This may include increasing the capacity of the drainage system, constructing detention ponds on site, or hardening an SSC against the effects of flooding caused by local precipitation.

5.5.5 Flood-Related Hazard Design Criteria

a) Unlike design strategies for seismic-related and wind-related hazards, it is not always possible to provide margin in the flood design of a SSC. For example, the simple fact that a site is inundated even if structural damage does not occur, it shall cause significant disruption (e.g., down time during the flood, clean-up). This is often unacceptable in terms of the economic impact and disruption of the mission-dependent function of the site. Under these circumstances, there is no margin, as used in the structural sense that can be provided when a site or SSC is inundated. Accordingly, the SSC shall be kept above the DBFL, if necessary, to ensure that its safety functions are not interrupted. If mitigation systems, such as watertight doors, sealants, etc. are used, manufacturer specifications should be applied.

g) The flood-related loads specified in ASCE/SEI 7-10, including hydrostatic, hydrodynamic, wave, and impact loads, shall be used for design of structures, roofs and walls, etc., considering event combinations listed in Table 5-4.

5.5.5.1 Design of FDC-1 SSCs

a) FDC-1 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category II, except that the DBFL shall be based on a return period of 500 years as required in Table 5-2 and Table 5-3. Event combinations that shall be considered are listed in Table 5-4. The building structural system shall be capable of withstanding the forces associated with the DBFL.

b) The occupant safety shall be ensured. Also, adequate time for warning shall be available to ensure that building occupants can be evacuated (i.e., 1 to 2 hours).

c) If the building is located above the DBFL, then structural and occupant safety requirements are met.

d) Where a structure cannot be constructed above the DBFL level, an acceptable design can be achieved by:

    i) Reducing the design basis flood hazard or providing flood protection for the site or for the specific structure, such that severe structural damage does not occur; and,

    ii) Developing emergency procedures in order to provide adequate warning and evacuation capability to provide for the safety of building occupants.

5.5.5.2 Design of FDC-2 SSCs

a) FDC-2 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category IV, except that the DBFL shall be based on a return period of 1000 years as required in Tables 5-2 and 5-3. Event combinations that shall be considered are listed in Table 5-4. The building structural system shall be capable of withstanding the forces associated with the DBFL.

b) For SSCs that cannot be located above the DBFL, an acceptable design can be achieved by the same measures described for FDC-1.

c) Emergency operation plans shall be developed to provide for occupant safety and to mitigate the damage to mission-dependent SSCs. These procedures may include installation of temporary flood barriers, removal of equipment to protected areas, anchoring vulnerable items, or installing sumps or emergency pumps.

d) As in the case of SSCs in FDC-1, the flood loads should be used in the building design.

5.5.5.3 Design of FDC-3 SSCs

a) FDC-3 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category IV, except that the DBFL shall be based on a return period of 10,000 years as required in Table 5-2 and Table 5-3. Event combinations that shall be considered are listed in Table 5-4. The building structural system shall be capable of withstanding the forces associated with the DBFL.

b) If the design objective is continued function of the facility, including confinement of hazardous materials and occupant safety, these shall be located above the DBFL.

c) If SSCs in this category cannot be constructed above the DBFL level, a design shall be developed that provides continued facility operation. The strategy shall mitigate the flood (i.e., reducing the flood hazards, hardening the facility, building a levee to prevent flood encroachment) to an extent that facility operations can continue.

d) For FDC-3 SSCs, the DBFL shall be mitigated such that the flood does not impact operations.

e) For SSCs that may be impacted by the DBFL, emergency operation plans shall be developed to evacuate personnel not involved in the emergency operation of the facility, secure hazardous materials, prepare the facility for possible extreme flooding and loss of power, and provide supplies for personnel who may have an extended stay on-site.

f) Emergency procedures shall be coordinated with the results of the flood hazard analysis, which provides input on the time variation of flooding, type of hazards to be expected and their duration.

g) The use of emergency operation plans is not an alternative to hardening a facility to provide adequate confinement unless all hazardous materials can be completely removed from the site.

5.5.5.4 Design of FDC-4 SSCs

a) FDC-4 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category IV, except that the DBFL shall be based on a return period of 25,000 years as required in Tables 5-2 and 5-3. Event combinations that shall be considered are listed in Table 5-4. The building structural system shall be capable of withstanding the forces associated with the DBFL.

b) Other design requirements for FDC-4 SSCs are the same as those for FDC-3.

5.5.5.5 Design of FDC-5 SSCs

a) FDC-5 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category IV, except that the DBFL shall be based on a return period of 100,000 years as required in Tables 5-2 and 5-3. Event combinations that shall be considered are listed in Table 5-4. The building structural system shall be capable of withstanding the forces associated with the DBFL.

b) Other design requirements for FDC-5 SSCs are the same as those for FDC-3.

5.5.6 Flood Design Practice for SSCs Below the DBFL Elevation

a) For SSCs located below the DBFL elevation, mitigation measures shall be designed such that the SSCs meet the structural requirements given in ASCE/SEI 7-10 and their respective safety functions.

b) In practice, a combination of structural and non-structural measures (i.e., flood warning and emergency operation plans) can be used to achieve the performance objectives.

c) To evaluate the effects of flood hazards, corresponding forces on structures shall be evaluated considering the event combinations given in Table 5-4.

d) Force evaluations shall consider hydrostatic and hydrodynamic effects, including the impact associated with wave action. In addition, the potential for erosion and scour and debris loads shall be considered.

e) Good engineering practice should be used to evaluate flood loads including the forces due to ice formation on bodies of water.

5.5.7 Site Drainage and Roof Design

a) For new construction the storm water-management system (i.e., street drainage, storm sewers, open channels, roof drainage) can be designed according to applicable procedures and design criteria specified applicable regulations.

b) Applicable local regulations shall be considered in the design of the site storm water management system. The minimum design level for the storm water management system is the 25-year, 6-hour storm.

c) Once the site and facility drainage design has been developed, it should be evaluated for the DBFL precipitation for each SSC.

d) The evaluation should consider the site-drainage area, natural and man-made watercourses, roof drainage, etc. The analysis shall also determine the level of flooding that could occur at each SSC.

e) The analyst may choose to evaluate the site storm water management system for the highest category DBFL as a limiting case. If the results of this analysis demonstrate that flooding does not compromise the site SSCs, then it may be concluded that the site storm water management system is adequate.

f) Note that local flooding in streets, parking lots, etc. may occur due to the DBFL precipitation. This is acceptable if the effect of local flooding does not exceed the design requirements. However, if flooding does have an unacceptable impact, increased drainage capacity and/or flood protection shall be required.

g) Building roof design should provide adequate drainage in accordance with applicable regulations.

h) Secondary drainage (i.e., overflow) should be provided at a higher level and have a capacity at least that of the primary drain.

i) Limitations of water depth on a roof are specified by applicable local regulations.

j) The roof should be designed to consider the maximum depth of water that could accumulate if the primary drainage system is blocked.

k) Roof drainage systems should be designed according to applicable regulations.

l) The drainage system should be verified as part of the site analysis for the DBFL (discussed above). In the case of rainfall, a limiting check of the roof system structural design should be made.

m) Ponding on the roof is assumed to occur to a maximum depth corresponding to the level of the secondary drainage outlet system (i.e., assuming the primary system has clogged). As part of this evaluation, the deflection of the roof due to ponding shall be considered.

n) The design of the roof should be adequate to meet the applicable codes. Design criteria for snow and rain-snow loads are defined in the applicable regulations.

o) In the design of roof systems for snow loads, the importance factor for FDC-1 and FDC-2 are 1.0 and 1.2, respectively, per ASCE/SEI 7-10.

p) For FDC-3, FDC-4, and FDC-5 an importance factor of 1.0 should be used.

5.5.8 Flood Protection and Emergency Operations Plans

a) For SSCs that may be exposed to flood hazards (i.e., are located below the DBFL), a number of design alternatives are available. Depending on the flood hazards that an SSC shall withstand, various hardening systems may be considered. These include:

   i) Structural barriers (e.g., exterior building walls, floodwalls, watertight doors);

   ii) Wet or dry flood proofing (e.g., waterproofing exterior walls, watertight doors);

   iii) Levees, dikes, seawalls, revetments; and,

   iv) Diversion dams and retention basins.

b) The design of structural systems (i.e., exterior building walls) shall be developed in accordance with applicable regulations.

c) Waterproofing requirements are also given in applicable design standards.

d) Guidelines for the design of earth structures such as levees, seawalls, etc. are provided in *Design of Small Dams , Design and Construction of Levees , and Shore Protection Manual*. Additional guidance for the design of diversion dams and retention basins can be found in COE, U.S. Bureau of Reclamation, and Soil Conservation Service.

e) Emergency operations plans are required in cases where the health and safety of onsite personnel shall be provided for and where the facility shall be secured to prevent damage or interruption of operations. The elements of an emergency operations plan are:

    i) Flood recognition system, which is the capability to identify impending floods and predicting their timing and magnitude;

    ii) Warning system, which are the procedures and means to provide warning to those in the affected areas;

    iii) Preparedness plan, which establishes the procedures, responsibility and capability (i.e., materials, transportation, etc.) to evacuate on-site personnel, secure vulnerable areas, etc.; and,

    iv) Maintenance plan; a program to insure that the emergency operation plan is up-to-date and operational.

f) Guidance for the development of the emergency operation plans can be found in emergency procedures developed for nuclear power plants, dams and local flood warning systems.

g) The development of the emergency operation plan should be coordinated with the results of the flood hazard assessment and local agencies responsible for flood forecasting.

h) The availability of warning time will vary depending on the type of flood hazard and local forecasting capabilities. Specific information on flood emergency procedures can be found in *Engineering Guidelines for the Evaluation of Hydropower Project*.

5.5.9 Considerations for Existing Facilities

a) SSCs in existing facilities may not be situated above the DBFL as defined in this standard. In this case, an SSC shall be reviewed to determine the level of flooding, if any, that can be sustained, without impacting the SSC functional requirements.

b) This is referred to as the Critical Flood Elevation (CFE). If the CFE is higher than the DBFL, then the criteria in Section 5.1 are not applicable.

c) This situation may not be unique for existing facilities. For new facilities, it may not be possible to situate all facilities above the DBFL, in which case other design strategies shall be considered. For example, it may be possible to wet proof an SSC, thus allowing some level of flooding to occur.

d) For each SSC, there is a critical elevation, which if exceeded, causes damage or disruption such that design requirements are not satisfied. The CFE may be located:

    i) Below grade due to the structural vulnerability of exterior walls or instability due to uplift pressures;

    ii) At the elevation of utilities that support SSCs; or,

    iii) At the actual base elevation of an SSC.

e) Typically, the first floor-elevation or a below-grade elevation (i.e., foundation level) is assumed to be the critical elevation. However, based on a review of an SSC, it may be determined that greater flood depths shall occur to cause damage (e.g., critical equipment or materials may be located above the first floor). If the CFE for an SSC exceeds the DBFL, then the design criteria is satisfied. If the CFE does not exceed the DBFL, options shall be considered to harden the SSC or relocate it.

6.0 Criteria, and Guidelines for Lightning Design

6.1 Lightning Categorization

For designing new facilities, while performing the systematic safety and hazard evaluation, the results of which would be used to determine the seismic and other NPH design category of SSCs (see Section 2), lightning hazards shall also be considered, and the SSCs that would need lightning protection to ensure their safety function shall be identified and designated as Lightning Category (LC) SSCs, irrespective of the failure consequences of these SSCs. In lightning prone areas, consideration should be given to providing lightning protection for bus shelters stations, or other small structures where personnel make seek shelter from the weather.

6.2 Lightning Design

6.2.1 LC SSCs shall be designed to preclude adverse consequences from lightning hazards, and/or shall be protected in accordance with NFPA 780-2011, *Standard for the Installation of Lightning Protection Systems, Annex L,* unless modified by the fire hazard analysis (FHA).

6.2.2 When lightning protection is required for a SSC, it shall be installed and maintained in accordance with NFPA 780-2011.

6.2.3 When the risk of lightning is high for exposed personnel, site management should issue warnings and permit pedestrians and workers to seek lightning and weather protected shelter.

6.2.4 Lightning protection for facilities containing explosives shall follow lightning protection requirements in the DOE-STD-0034, *Explosives Safety*.

7.0 Requirements, Criteria, and Guidelines for Snow Design

Snowfall is a form of precipitation such as rainfall, therefore the snow categorization of the SSCs shall be the same as the FDC-1 through FDC-5 as discussed in Section 5.0.

7.1 Design Categories FDC-1 and FDC-2

For FDC-1 and FDC-2 SSCs, the requirements and criteria in ASCE 7-10 shall be used for the snow design. An Importance Factor of 1.0 shall be used for FDC-1 SSCs and an Importance factor of 1.2 shall be used for FDC-2 SSCs.

7.2 Design Categories FDC-3, FDC-4, and FDC-5

The Commentary in ASCE 7-10 provides information about probabilistic snow studies which can be used to determine the ground snow loads for the longer return periods used for the design of FDC-3, FDC-4, and FDC-5 SSCs. Site-specific probabilistic studies using the probabilistic methods defined in ASCE 7-10 shall be performed to define the ground snow loads for FDC-3, FDC-4, and FDC-5 SSCs. In lieu of site-specific probabilistic studies, the probabilistic data provided in the Commentary of ASCE 7-10 can be used to determine the ground snow loads for FDC-3, FDC-4, and FDC-5 SSCs, if considered applicable.

The ground snow loads shall be used with ASCE 7-10 to determine the design snow loads for the design of the SSCs, using an Importance factor of 1.0. The snow loads shall be used in the applicable load combinations from the industry nuclear related codes for extreme loading conditions.

8.0 Requirements, Criteria, and Guidelines for Volcanic Eruption Design

Designing facilities to withstand the effects of local hazards such as lava flows, ballistic projections, pyroclastic flows, mudflows, and ground deformation is rarely feasible. Such hazards should be mitigated by siting facilities far enough from active volcanoes to eliminate these hazards.

8.1 Applicable Sites

Volcanic eruptions may pose hazards to select DOE sites in the Western United States (e.g., Idaho National Laboratory, Hanford). Volcanic hazards shall be assessed at DOE sites and facilities lying within 400 kilometers (approximately 250 miles) of a volcanic center that erupted within the Quaternary Period (i.e., 2.6 million years before present). This Section only applies to DOE facilities with envisioned life spans up to 100 years. This Section does not apply to facilities such as geologic repositories with extended performance periods.

8.2 Volcanic Hazard Assessment

Sites within 400 kilometers of a Quaternary volcano shall compile a site volcanic hazards assessment (VHA). Potential volcanic hazards to be assessed include:

1) Ashfall (tephra);
2) Lava flows;
3) Ballistic projections;
4) Pyroclastic flows;
5) Mudflows (lahars);
6) Low-level proximal seismic activity;
7) Ground deformation;
8) Tsunami (this is addressed separately in Section 5);
9) Atmospheric effects, such as lightning and downburst winds; and
10) Emissions of gasses that result in acid rains.

8.3 Characterization of Volcanic Hazards

8.3.1 Volcanic eruptions are classified on a volcanic explosivity index (VEI) ranging from 0 to 8, with 8 representing the most explosive, voluminous eruptions (Newhall and Self, 1982). Higher VEI eruptions are less common than low VEI eruptions.

8.3.2 World-wide eruption data (Newhall and Hoblitt, 2002) indicate that ashfall impacts from eruptions with a VEI of less than 6 will be negligible at distances beyond 400 km. At such distances, airborne particulates would likely have effects on a facility similar to the effects of a dust storm, and roof loads from ash accumulation would be bounded by loads for non-hazardous facilities established in ASCE/SEI 7-10.

8.3.3 A VEI of 6 is selected as a benchmark since volcanic systems in the Western U.S. are unlikely to produce eruptions at VEI 6 or above in the life span of a facility. Such catastrophic eruptions generally occur only at highly active centers that would demonstrate indicators of such potential decades in advance.

8.3.4 For facilities within 400 km of a volcano with Quaternary activity, the volcanic hazards shall be assessed with a graded approach, considering the distance from the volcano(es) and the level of volcanic activity.

8.3.5 For facilities beyond 100 km from the closest Quaternary volcano, only the hazards posed by ashfall and gases need be evaluated.

8.3.6 The hazard characterization for facilities between 100 km and 400 km from a Quaternary volcano shall produce a map of all Quaternary volcanoes within 400 km, including distances from the volcanoes to the site boundary. Information on the eruption history of these volcanoes shall be assembled from available literature, such as U.S. Geological Survey publications, DOE contractor technical reports, and published geology literature. This information shall include parameters such as eruption ages, estimated volumes, eruption characteristics/explosivity, and extent of ashfall, if known.

8.3.7 Ash deposits are highly erodible and as such, poorly preserved in the geologic record. Ashfall thicknesses and eruption volume data may be sparse and highly uncertain. Most volcanoes and volcanic fields in the Western U.S. have been studied to some degree in the past, and parameters such as most recent eruption age and eruption characteristics should be available for most all of them.

8.3.8 Eruption characteristics are much easier to assess than eruption volumes, frequencies, and spatial extent.

8.3.9 Given the past research on Western U.S. volcanic centers, an adequate VHA for DOE facilities should require minimal additional data collection. In cases where data can be collected, at reasonable time and expense, that will significantly increase understanding of the hazard posed by a volcano, then such data collection is prudent. An example would be a radiometric age on an identified, but undated Quaternary ash deposit from a volcanic center within 400 km of a facility.

8.3.10 Well-characterized volcanoes outside the Western U.S. may serve as useful analogues for additional data on ashfall parameters (i.e., distances and thicknesses), assuming they demonstrate eruption characteristics similar to the volcanoes of interest to DOE sites.

8.3.11 Volcano characterization is just the first step in a VHA. The wind conditions shall also be characterized, as the wind will control the distribution pattern of an ashfall. Meteorological data shall be assembled to characterize the prevailing winds around the volcanoes of interest. Ideally, these data shall include probabilities by azimuth sector at various altitudes. Information on eruption probabilities, eruption characteristics, or volumes, and wind probabilities can be used to develop an annual frequency of exceedance of ashfall with a given thickness, at a given distance from a volcano. Hoblitt and Scott (2011) provide an example of such a distribution for DOE's Hanford Site from the Cascade Range volcanoes.

8.3.12 In most cases, eruption data from relevant volcanoes will be too sparse to construct a probabilistic distribution as Hoblitt and Scott (2011) do for Hanford. With less data, a Monte Carlo simulation to capture the expected ranges of eruption frequency, volume, and wind direction can be constructed to produce ashfall hazard curves (i.e., thickness versus probability of exceedance) for given locations surrounding a volcano.

8.3.13 If a facility has ventilation or other systems likely to be impacted by airborne ash, the airborne ash density and duration of ashfall are important considerations. Any existing data on eruption durations or ash cloud densities from volcanoes similar to those of interest shall be assembled. In the absence of data, assume that the maximum design ashfall thickness falls over a period of 12 hours. From these values an estimate of cloud density in grams of ash per cubic meter shall be obtained.

8.3.14 For facilities within 100 km of a Quaternary volcano, the hazards posed by lava flows, pyroclastic flows, and mudflows shall be addressed.

8.3.15 If local topography would prevent any of these hazards from impacting the facility, then this shall be justified and no further evaluation is required. If topography is not an adequate barrier, then geologic data describing the past extent of such features shall be assembled and evaluated.

8.3.16 Geologic data are not likely to support a probabilistic assessment of these hazards. An evaluation of the facility impact from the largest credible lava flows, pyroclastic flows, and mudflows by a deterministic analysis shall be performed.

8.4 Design Considerations for Volcanic Hazards

8.4.1 The primary design considerations relative to volcanic hazards are structural loading and ash impact on ventilation and other mechanical and electrical systems. To determine appropriate design loads for DOE facilities, target performance goals analogous to those for seismic design criteria, as listed in ANSI/ANS-2.26-2004 Table A.1, shall be considered. Thus, for facilities of SDC-3 or higher, target performance goals for failure in the range of 10^{-4} to 10^{-5} per year shall be considered.

8.4.2 If SSC unmitigated failure consequences are no more severe than SDC-2 as described in ANSI/ANS-2.26-2004 Table 1, then the facility and SSCs may use the design standards of ASCE/SEI 7-10.

8.4.3 For structural design considerations, risk reduction factors may be used to increase the annual probability of hazard exceedance above the performance goals. An example employing risk reduction factors for ashfall at the Hanford Site appears in Conrads (1996).

8.4.4 Structural design shall consider ash density and the impact of precipitation combined with an ashfall. Ash density estimates for volcanoes of interest are likely sparse. Ash density generally decreases with distance from a volcano, and a typical range is 0.4-0.7 g/cm3. Saturating volcanic ash with rainfall or melted snow can increase density by 50-100 percent or more, on occasion exceeding a density of 2.0 g/cm3 (USGS, 2011). Ash particle sizes are very effective for nucleating raindrops, so if an ash cloud interacts with a precipitation front, heavy rainfall and ash saturation is likely. Site meteorological data shall be considered in calculating the probability of ashfall combining with rainfall, and an appropriate ash density derived.

8.4.5 Most likely non-structural impact of ashfall is on ventilation systems. Airborne ash density estimates, which as stated above may be very imprecise, and likely eruption duration of 12 hours minimum shall be considered in ventilation system design. Key considerations will be filter loading time, ability to keep critical systems in operation during filter change-out, and availability of spare filters.

8.4.6 Impacts of ashfall and volcanic gases on other mechanical and electrical systems shall also be evaluated.

8.4.7 Facility designs are unlikely to mitigate effects from the largest credible lava flows, pyroclastic flows, and mudflows that might impact a facility within 100 km of a volcanic eruption. However, these phenomena would most likely strike with some advance warning. Therefore, facilities at risk shall develop administrative controls to ensure safe process shutdown and personnel evacuation if the facility is endangered by an eruption.

8.4.8 Secondary effects of these phenomena shall also be considered. For example, lava flows can block rivers that can then flood, as discussed in Section 5.

8.5 Additional Reading

In contrast to extensive work on seismic, wind, and flood hazards, little guidance has been published on volcanic hazard characterization and mitigation at nuclear facilities.

8.5.1 A draft International Atomic Energy Agency (IAEA) safety guide, DS405, *Volcanic Hazards in Site Evaluation for Nuclear Installations*, provides guidance on the assessment of volcanic hazards at nuclear facilities world-wide.

8.5.2 Hill et al. (2009) provide an excellent overview on the topic, but as with the forthcoming IAEA safety guide, it is most useful for facilities located outside the Western U.S., near much more active volcanoes.

8.5.3 Other references include:

1) Conrads, T.J., 1996, *Volcano Ashfall Loads for the Hanford Site*, Westinghouse Hanford Company, WHC-SD-GN-ER-30038, Rev. 0.

2) Hill, B.E., Aspinall, W.P., Connor, C.B., Komorowski, J.-C., and Nakada, S., 2009, *Recommendations for assessing volcanic hazards at sites of nuclear installations*, in Volcanic and Tectonic Hazard Assessment for Nuclear Facilities, C.B. Connor, N.A. Chapman, and L.J. Connor, eds., Cambridge University Press, 638 p.

3) Hoblitt, R.P., and Scott, W.E., 2011, *Estimate of Tephra Accumulation Probabilities for the U.S. Department of Energy's Hanford Site, Washington*, U.S. Geological Survey Open-File Report 2011-1064

4) Newhall, C.G., and Hoblitt, R.P., 2002, *Constructing event trees for volcanic crises*, Bulletin of Volcanology, v. 64, pp. 3-20.

5) U.S. Geological Survey (2011), *Volcanic Ash: Effects & Mitigation Strategies*, http://volcanoes.usgs.gov/ash/build/index.html, referenced on March 16, 2011.

9.0 Evaluation and Modification of Existing Facilities

9.1 Periodic Evaluation of Existing Facilities

9.1.1 The program of reviewing existing facilities for compliance with NPH provisions of DOE O 420.1C shall include evaluations of the following items that were used to establish the current safety basis of the facility:

9.1.1.1 NPH data and data collection methods;

9.1.1.2 NPH evaluation methods;

9.1.1.3 Methods and criteria used to establish the NPH design categories of the SSCs; and

9.1.1.4 SSC design and analysis methods and criteria.

9.1.2 These items shall be reviewed to evaluate if there have been any significant changes that would warrant updating the safety basis of the facility. This review shall be performed periodically at least every 10 years. It shall be performed by a subject matter expert or a team of subject matter experts, depending on the highest NPH design category of SSCs in a facility.

9.2 Modification of Existing Facilities

9.2.1 For existing facilities that are not undergoing modifications for programmatic reasons, it is not necessary to apply the NPH design categorization criteria given in this standard in a backfit sense.

9.2.2 The design of SSCs in an existing facility that needs major modifications (defined in DOE-STD-1189-2008) shall be based on the methods and criteria given in this standard with the following caveats. Backfit analyses should examine:

9.2.2.1 The need to upgrade interfacing SSCs in accordance with these criteria, and

9.2.2.2 Whether there should be relief for the modification from the design requirements that application of these criteria in design would imply.

9.2.3 In evaluating the need for upgrading, existing SSCs should follow or, at least, be measured against the NPH criteria provided in this document. For SSCs not meeting these criteria and which cannot be easily remedied, budgets and schedule for required strengthening shall be established on a prioritized basis based on a back-fit analysis.

9.2.4 Priorities should be established on the basis of NPH design category (e.g., SDC, WDC, FDC), cost of strengthening, and margin between as-is SSC capacity and the capacity required by the criteria in this standard. For SSCs which are close to meeting the criteria in this standard, the risk from non-compliance is likely to be small and it may not be cost effective to strengthen the SSC in order to obtain a small reduction in risk. As a result, as specified below, some relief from the criteria in this standard is permitted for evaluation of existing SSCs.

9.2.5 For facilities with a remaining service life of 5 years or less, it is permissible to perform design evaluations using NPH exceedance probability equal to twice that specified in this standard.

9.2.6 For facilities with a remaining service life of 5 years or less, it may not be necessary to upgrade the facility for NPH mitigation unless the presence of hazardous materials or other special conditions present an “exceptionally high risk” to occupants or the public at large.

9.2.7 For facilities with a remaining service life of more than 5 years but less than or equal to 40 years, it is permissible to perform design evaluations using NPH exceedance probability equal to that specified in this standard multiplied by a factor equal to [2 – (L - 5)/35], where, L = remaining life in years.

9.2.8 For facilities with a remaining service life of more than 40 years, design evaluations shall be performed using NPH exceedance probability equal to that specified in this standard.

9.2.9 The relief given in paragraphs 9.2.5 and 9.2.6 above is based on the assumption that the slope of the hazard curve is such that doubling the hazard annual probability of exceedance would have the effect of reducing the NPH demand in the SSC evaluation by no more than 20%. This relief is conceptually consistent with the intent of the Federal Program developed by the Interagency Committee on Seismic Safety in Construction.

10.0 Quality Assurance and Peer Review

The activities related to the design, construction, and evaluation of SSCs performed to meet the criteria given in this standard shall meet the applicable quality assurance (QA) and peer review requirements of 10 CFR Part 830. DOE O 414.1 (CHG 1), ASCE/SEI 43-05, and ANSI/ANS 2.29-2008, as given in the following paragraphs:

10.1 The QA and peer review should be conducted within the framework of a:

> "graded approach" with increasing level of rigor employed from Performance Category 1 to 5. The "graded approach" defined in ANSI/ANS 2.26-2004 for seismic hazard shall also be applied for other NPHs.

10.2 When applicable, the QA and peer review provisions given in ASCE/SEI 43-05 for seismic design and evaluation shall also be used in the design and evaluation for other NPHs.

10.3 If any QA or peer review requirement in one of the above-listed documents for a given NPH design, construction, or evaluation activity is in conflict with that in another of these four documents, the general hierarchy shall be as follows, except when the provision of a particular document is explicitly applicable for the given activity in which case the later shall be used:

1) 10 CFR Part 830;
2) DOE O 414.1 (CHG 1);
3) ASCE/SEI 43-05; and
4) ANSI/ANS 2.29

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Appendix A: Glossary

This glossary explains important terms in this standard. To the extent practical, standard definitions have been used. In some cases, the general definitions have been supplemented in order to explain more fully how the term is used in this standard.

Enhanced Fujita (EF) Scale: A rating system originally devised (Fujita [1]) to facilitate categorizing tornadoes according to the damage they produce and later modified (Enhanced Fujita [2]) and adopted by the National Weather Service. Enhanced Fujita (EF) scale winds are defined to apply at the 33 ft (10 m) height. [Source ANSI/ANS 2.3-2011]

Hazard Curve: Curve that gives the probability of a certain ground motion parameter [usually the peak ground acceleration (PGA), peak ground velocity (PGV), or response spectral values] being exceeded. Hazard curves are generally generated for periods of exposure of one year, and they give annual probabilities of exceedance. [Source ANSI/ANS-2.27-2008]

Limit State (LS): The limiting acceptable deformation, displacement, or stress that a structure, system, or component (SSC) may experience during or following an earthquake and still perform its safety function. Four limit states are identified and used by ANSI/ANS-2.26-2004 and ASCE/SEI 43-05. [Source ANSI/ANS-2.27-2008]

Risk Category: A categorization of buildings and other structures for determination of flood, wind, snow, ice, and earthquake loads based on the risk associated with unacceptable performance. [Source ASCE/SEI 7-10]

Seismic Design Category (SDC): A category assigned to an SSC that is a function of the severity of adverse radiological and toxicological effects of the hazards that may result from the seismic failure of the SSC on workers, the public, and the environment. SSCs may be assigned to SDCs that range from 1 through 5. For example, a conventional building whose failure may not result in any radiological or toxicological consequences is assigned to SDC-1; a safety-related SSC in a nuclear material processing facility with a large inventory of radioactive material may be placed in SDC-5. ANSI/ANS-2.26-2004 provides guidance on the assignment of SSCs to SDCs. [Source ANSI/ANS-2.27-2008]

Target Performance Goal: Target mean annual frequency of an SSC exceeding its specified limit state. Target performance goals of $1x10^{-4}$/year, $4x10^{-5}$/year, and $1x10^{-5}$/year are used in ASCE/SEI 43-05 for SSCs defined at SDC-3 or higher. [Source ANSI/ANS-2.27-2008]

Appendix B: Abbreviations and Acronyms

ANS	American Nuclear Society
ANSI	American National Standards Institute
APC	Atmospheric Pressure Change
ASCE	American Society for Civil Engineers
ASER	Annual Site Environmental Report
CEUS	Central and Eastern United States
CFHA	Comprehensive Flood Hazard Assessment
COE	Corps of Engineers
D	Dead Load
DBFL	Design Basis Flood Level
DOE	Department of Energy
DRS	Design Response Spectra
EIS	Environmental Impact Statement
FDC	Flood Design Category
FEMA	Federal Emergency Management Agency
FIA	Flood Insurance Administration
FSA	Flood Screening Analysis
G	Guide
I	Importance Factor
IBC	International Building Code
L	Live Load
LS	Limit State
NCDC	National Climatic Data Center
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NPH	Natural Phenomena Hazard

NRC	Nuclear Regulatory Commission
NSSFC	National Severe Storms Forecast Center
NTTAA	National Technology Transfer and Advancement Act
NUREG	NRC technical document
NWS	National Weather Service
O	Order
PBL	Planetary Boundary Layer
PEIS	Programmatic Environmental Impact Statement
PFHA	Probabilistic Flood Hazard Assessment
PPRG	Participatory Peer Review Group
PWHA	Probabilistic Wind Hazard Assessment
QA	Quality Assurance
SDC	Seismic Design Category
SFE	Supercritical Fluid Extraction
SME	Subject Matter Expert
SSC	Structure System and Component
STD	Standard
T	Self Straining Force
TBD	To be determined
USGS	United States Geological Survey
VPEC	Velocity Pressure Exposure Coefficient
WDC	Wind Design Category

Appendix C: Effects of Flooding

C.1 Causes and Sources of Flooding and Flood Hazards

There are a number of meteorological and hydrological phenomena that can cause flooding at a site. For each cause or source of flooding, a facility may be exposed to one or a number of flood hazards. In most cases, the principal hazard of interest is submergence or inundation. However, the damage potential of a flood is increased if there are impact or dynamic forces, hydrostatic forces, water-borne debris, etc. Table C-1 lists the various sources or causes of flooding that can occur and the particular hazards they pose. From the table, one notes that many of the causes or sources of flooding may be interrelated. For example, flooding on a river can occur due to dam or levee failure or to precipitation.

In most cases, flood hazards are characterized in terms of the depth of flooding that occurs on site. Depth of inundation is the single most relevant measure of flood severity. However, the degree of damage that is caused by flooding depends on the nature of the hazard. For example, coastal sites experience significant damage due to wave action alone, even if the site is not completely inundated by a storm surge. Similarly, high-velocity flood waters on a river add substantially to the potential for loss of life and the extent of structural damage. In many cases, other hazards - such as wave action, sedimentation, and debris flow - can compound the damage caused by inundation.

C.2 Flooding Damage

In many ways, flood hazards differ significantly from other natural phenomena. As an example, it is often relatively easy to eliminate flood hazards as a potential contributor to damage at a site through strict siting requirements. Similarly, the opportunity to effectively utilize warning systems and emergency procedures to limit damage and personnel injury is significantly greater in the case of flooding than it is for seismic or extreme winds and tornadoes.

The damage to buildings and the threat to public health vary depending on the type of flood hazard. In general, structural and nonstructural damage occur if a site is inundated. Depending on the dynamic intensity of on-site flooding, severe structural damage and complete destruction of buildings can result. In many cases, structural failure may be less of a concern than the damaging effects of inundation on building contents and the possible transport of hazardous or radioactive materials.

For hazardous facilities that are not hardened against possible on-site and in-building flooding, simply inundating the site can result in a loss of function of critical components required to maintain safety and breach of areas that contain valuable or hazardous materials.

Structural damage to buildings depends on a number of factors related to the intensity of the flood hazard and the local hydraulics of the site. Severe structural damage and collapse can occur as a result of a combination of hazards such as flood stage level, flow velocity, debris or sediment transport, wave forces, and impact loads. Flood stage is quite obviously the single most important characteristic of the hazard (flood stages below grade generally do not result in severe damage).

In general, the consequences of flooding increases as flooding varies from submergence to rapidly moving water loaded with debris. Submergence results in water damage to a building and its contents, loss of operation of electrical components, and possible structural damage resulting from hydrostatic loads. Structural failure of roof systems can occur when drains become clogged or are inadequate, and parapet walls allow water, snow, or ice to collect. Also, exterior walls of reinforced concrete or masonry buildings (above and below grade) can crack and possibly fail under hydrostatic conditions.

Dynamic flood hazards can cause excessive damage to structures that are not properly designed. Where wave action is likely, erosion of shorelines or river banks can occur. Structures located near the shore are subject to continuous dynamic forces that can break up a reinforced concrete structure and at the same time undermine the foundation. Buildings with light steel frames and metal siding, wooden structures, and unreinforced masonry are susceptible to severe damage and even collapse if they are exposed to direct dynamic forces. Reinforced concrete buildings are less likely to suffer severe damage or collapse. Table C-2 summarizes the damage to buildings and flood-protection devices that various flood hazards can cause.

The transport of hazardous or radioactive material represents a major consequence of on-site flooding if confinement buildings or vaults are breached. Depending on the form and amount of material, the effects could be long-term and widespread once the contaminants enter the ground water or are deposited in populated areas.

Table C-1
Causes of Flooding

Source/Cause	Hazard
River flooding/precipitation, snow melt, debris jams, ice jams	Inundation, dynamic forces, wave action, sedimentation, ice loads
Dam failure/earthquake, flood, landslide, static failure (e.g., internal erosion, failure of outlet works)	Inundation, erosion, dynamic loads, sedimentation
Levee or dike failure/earthquake, flood, static failure (e.g., internal erosion, subsidence)	Inundation, erosion, dynamic loads, sedimentation
Precipitation/storm runoff	Inundation (ponding), dynamic loads (flash flooding)
Tsunami/earthquake	Inundation, dynamic loads
Seiche/earthquake, wind	Inundation, dynamic loads
Storm surge, usually accompanied by wave action/hurricane, tropical storm, squall line	Inundation, dynamic loads
Wave action	Inundation, dynamic loads
Debris	Dynamic loads

Table C-2
Causes of Flood Damage

Hazard	Damage
Submergence	Water damage to building contents; loss of electric power and component function; settlements of dikes, levees; levee overtopping
Hydrostatic loads	Cracking in walls and foundation damage; ponding on roofs that can cause collapse; failure of levees and dikes due to hydrostatic pressure and leakage
Dynamic loads	Erosion of embankments and undermining of seawalls. High dynamic loads can cause severe structural damage and erosion of levees

Appendix D: Additional Guidance on Flood-Related Hazard Assessments

The following hydrologic events that are potential sources of flooding shall be included in the flood hazard assessment:

(1) River flooding;

(2) Levee or dam failure;

(3) Flood runoff/drainage;

(4) Tsunami;

(5) Seiche;

(6) Storm surge;

(7) Wave and run-ups;

(8) Groundwater;

(9) Water-carried debris; and,

(10) Mud flows.

For each of these potential sources of flooding, appropriate information on topography, meteorological conditions, results of existing flood analyses, stage-discharge data, etc., that are necessary to determine and analyze the source shall be collected as specified in Section 4 of this standard.

The flood screening analyses shall determine potential flooding due to multiple sources and other possible chains of events.

For each of the sources of potential flooding, simple criteria (without performing any analysis other than analysis by reference) shall be provided establishing whether the site is affected by potential flooding from this source. These criteria include the applicable physical arguments that certain sources not present are very unlikely or that their consequences on the site are negligible.

For the sources of flooding for which no clear basis has been established to discard them as potential flood hazards to the site, a preliminary flood hazard analysis shall be performed.

A preliminary flood hazard analysis is performed for all sources of flooding identified as having potential impacts on the site. This analysis shall provide a measure of the magnitude and probability of occurrence of extreme events. This analysis does not need to be comprehensive and can be based on existing studies. For example, it is sufficient to use flood insurance studies or equivalent, that estimate flood probability to $2x10^{-3}$ per year to measure the magnitude and probability of occurrence of river flooding, and extend these results to a lower probability value (10^{-5} per year to 10^{-3}per year) (Kite, 1988). Furthermore, the results of any available existing flood frequency analyses should be compared to the results of a preliminary flood hazard analysis.

A preliminary flood hazard analysis provides estimates of the probability of floods and an assessment of the uncertainty in the hazard estimate. Rivers or streams are the most common sources of flooding. For this type of flooding, a simplified acceptable method to estimate the probability that specified elevations at the DOE sites will be exceeded consists of the following steps (McCann and Boissonnade, 1988a):

Step 1: Compile, obtain and update a data base of peak discharge as described in Section 4 of this standard.

Step 2: Estimate the probability of exceedance of selected peak discharge levels with associated uncertainty.

An acceptable methodology using stream flow data, and including uncertainty estimates due to the statistical model selected and limited flood data is provided by [31].

Step 3: Determine the stage-discharge relationship (a relationship between flow discharge and flood stage).

Stage-discharge relationships derived from historical floods, hydraulic evaluation (e.g., Manning's equation, step-backwater calculation), and channel geometry data. Uncertainty in estimating these relationships shall be accounted for

Step 4: Transform the probability-discharge frequency to stage frequency to determine the probability of exceeding selected stage elevations using the stage-discharge relationship.

Existing dam failure analyses performed as part of emergency action plans shall be used if they are available. Otherwise, acceptable simplified analysis methods to assess flooding due to dam failure include those given by [32] and [15].

Acceptable hydraulic models to assess runoff or ponding include those given by [9] or [12].

The main results of a preliminary flood hazard assessment consists of the family of flood hazard curves that describes the annual probability that specified flood elevations at the site will be exceeded. A probability weight is assigned to each curve that quantifies the uncertainty in the analysis (see for example [31]). Based on the family of hazard curves, a mean flood hazard curve can be calculated.

Estimates of wave height and run-ups shall be made using criteria defined in [33].

In the event that more than one cause of flooding has been identified and for which flood hazard curves have been determined, a composite flood hazard assessment shall be performed.

Appendix E: Additional Guidance on Wind-Related Hazard Evaluations

An acceptable method to estimate the annual probability that specified wind speeds at the site will be exceeded can be described by the following three-step technique:

- Step 1: Select a data set of annual extreme wind speeds from a weather station or meteorological monitoring station near the site of interest. No recorded wind speeds from anemometers located on building roofs near the edges, sheltered by parapets or neighboring buildings, or too close to the roof surface (less than 5 feet (1.5 meters)) shall be used. Exposure criteria are identified in ANSI/ANS-3.11-2010.

- Step 2: Correct the annual extreme wind speeds to an anemometer height of 33 ft (10 meters) above ground in flat, open terrain using appropriate wind power law methodologies.

- Step 3: Estimate the annual probability of exceedance of selected wind speeds with its associated uncertainty.

Several statistical models are available to estimate frequency of winds. An estimate of the models fitting the data should be performed. Guidance may be found in NUREG/CR-4461, Rev.2, or Boissonnade, A, et al (2000).

The variability associated with estimating the parameters of the statistical models shall be accounted for. For sites within 100 km (62 miles) of a coastline, a hurricane wind PWHA provides estimates of the probability of exceeding wind speeds at a given location and an assessment of the uncertainty in the hazard estimates. Monte Carlo simulation techniques or an alternative method may be used to assess the probability that specified wind speeds will be exceeded at the site. This procedure consists of the following five steps:

- Step 1: Select a data set of hurricanes within 250 km (155 miles) from the site.

- Step 2: Estimate the probability distributions of the hurricane parameters (e.g., occurrence, central pressure, direction, landfall location, and forward translational speed).

- Step 3: Select a wind field model to calculate maximum wind speeds as functions of the hurricane parameters (these should include frictional effects of land and local site conditions).

- Step 4: Perform a Monte Carlo simulation to simulate the hurricane parameters and determine the associated maximum wind speed at the site.

- Step 5: Assess the exceedance probabilities of wind speeds. A preliminary hurricane wind hazard analysis may be performed to assess the magnitude of hurricane wind speeds by using reported results of hurricane hazard analyses.

A tornado hazard analysis generally consists of the following five steps:

- Step 1: Compile, obtain, and update as necessary a data set of tornadoes for the area;

- Step 2: Develop occurrence-intensity relationship;
- Step 3: Develop area-intensity relationship;
- Step 4: Calculate probability of a point experiencing tornado intensity; and,
- Step 5: Calculate probability of tornado wind speeds exceeding specified values.

The tornado hazard models described in NUREG/CR-4461, Rev.2, or in Boissonnade et. al. (2000), are acceptable for use in conducting a site-specific tornado probabilistic hazard analysis, provided the model uses the latest historical tornado data. In addition, the rationale given for wind borne missile criteria in UCRL-CR-13587 could be used.