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DOE STANDARD

Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities

U.S. Department of Energy **AREA NPHZ**
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Foreword

Department of Energy (DOE) Standard (STD)-1020-2012, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities,* provides criteria and guidance for the analysis and design of facility structures, systems, and components (SSCs) that are necessary to implement the requirements of DOE Order (O) 420.1C, *Facility Safety*, and to ensure that the SSCs will be able to effectively perform their intended safety functions 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., design basis flood water level relative to the location of an SSC that is vulnerable to inundation, the state of SSC deformation under various NPH loads, limit states under dynamic loads , etc.), and grading the SSCs into more than one NPH design category, based on the consequences of SSC failure when subjected to NPH events;

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

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

The focus of this Standard is on the analysis and design of new facilities. For existing facilities, evaluations of NPH capabilities should have already been performed utilizing the previous version of this and other related NPH standards. This Standard also provides criteria and guidance for major modifications to existing hazard category 1, 2, and 3 nuclear facilities, and for 10-year NPH reassessments, which could potentially trigger design reviews of existing facilities if significant increases in NPH design loads or risks are identified.

Prior to this revision of DOE-STD-1020, DOE used the following DOE guide (G) and standards to support implementation of the NPH requirements:

- **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 Guidelines 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 this new DOE-STD-1020-2012, 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 DOE-STD-1021 are replaced by American National Standards Institute (ANSI)/American Nuclear Society (ANS)-2.26-2004 (R2010), *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design,* and this revision of DOE-STD-1020*.* The wind, precipitation (inclusive of rain, snow, and ice), 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 DOE-STD-1022 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 provided in this revision.

- **DOE-STD-1023-95:** This standard is superseded. The seismic hazard assessment provisions of DOE-STD-1023-95 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 provided 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 DOE Technical Standards Program website.

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, precipitation, 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 Department of Energy (DOE) Standard (STD)-1020-2012, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities,* provides criteria and guidance for the analysis and design of facility structures, systems, and components (SSCs) that are necessary to implement the requirements of DOE Order (O) 420.1C, *Facility Safety,* and to ensure that the SSCs will be able to effectively perform their intended safety functions 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

Earlier versions of this Standard have directly provided 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* that encourages the use of industry building codes and voluntary consensus standards, DOE has actively participated with standards development organizations, (e.g., the American Nuclear Society (ANS), the American Society of Civil Engineers (ASCE), the Structural Engineering Institute (SEI)), to develop the following five voluntary consensus standards associated with the seismic and extreme winds design of nuclear facilities:

- American National Standards Institute (ANSI)/ANS-2.26-2004, *Categorization of Nuclear Facility Structures, Systems, and Components*;
- 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*;
- ANSI/ANS-2.3-2011, *Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facilities; and,*
- ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*.

The first four of these voluntary consensus standards were adopted by DOE, with some modifications, as stated in DOE-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, DOE-STD-1021-93, DOE-STD-1022-94 and DOE-STD-1023-95 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-1189-2008 and consolidates, updates, and incorporates criteria and guidance for other NPHs 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 this revision of DOE-STD-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 DOE Technical Standards Program website. Further, information in Appendices B through E of DOE-STD-1020-2002, which is not included in this revision of DOE-STD-1020, provides background on the previous NPH criteria and design that can be useful when evaluating current designs and understanding general NPH design philosophies. The Department is evaluating an update of this information and incorporation into a separate handbook.

1.3. Applicability and Scope

This Standard has the same applicability as Chapter IV of Attachment 2 in DOE O 420.1C, i.e., it is applicable to all government-owned and government-leased nuclear and non-nuclear facilities and sites.

The provisions of this Standard apply only to new facilities and major modifications, unless triggered by periodic NPH assessment and upgrade requirements.

This Standard addresses the following NPHs: earthquakes, extreme winds (inclusive of tornado, hurricane, and extreme straight line winds), floods, lightning, precipitation (inclusive of snow, rain, and ice), and volcanic eruptions. Wildland fires that may result from certain NPHs are not addressed in this Standard; rather, they are addressed in DOE-STD-1066-2012, *Fire Protection*.

Several other NPHs may require analysis and design consideration at certain sites, although no guidance for hazard analysis or design for these phenomena is provided in this Standard. These phenomena include drought, fog, frost, extreme temperatures, landslides, subsidence, surface collapse, uplift, and waterspouts. DOE and facility operators should discuss which, if any, of these phenomena need consideration, based on both site and facility characteristics.

Several documents have been referenced in this Standard, both for establishing or augmenting requirements and to provide guidance. Even though only the current versions of these documents have been cited in this Standard, the use of the applicable provisions in the latest version of a cited reference is preferable, but not mandatory, provided that the use of such a later version is consistent with other provisions of this Standard. Also, when an SSC is designed by mixing the provisions from two versions of a cited reference, the resulting design shall not be less conservative than that resulting from the application of the latest version alone.

1.4. Overview and Organization

The NPH analysis and design process involves the following steps:

Step 1: Siting new facilities to avoid active geologic faults, areas of instability subject to landslides, and areas of likely soil liquefaction. Also, unless impractical from cost and strategic considerations, facilities shall not be located below the design basis flood level (DBFL) determined from a probabilistic flood hazard analysis. Special attention shall be given to sites potentially subject to flooding from upstream dams or reservoirs, including seismically induced failures.[1]

Step 2: Establishing the performance requirements for SSCs in terms of parameters that define failure of their safety functions (e.g., flood water level relative to the location of a SSC that is vulnerable to inundation, the state of SSC deformation under various NPH loads, limit states (LS) under seismic loads, etc.), that can be determined from the NPH design category (NDC) which is based upon the consequences of SSC failure when subjected to NPH events.

Step 3: Calculating NPH demands on SSCs resulting from NPH events in terms of parameters that define failure of their safety functions.

Step 4: Designing (or, for existing facilities, design evaluation) SSCs to ensure their ability to maintain required functionality when subjected to demands of NPH events.

Section 2 of this Standard provides generic NPH criteria and guidance for Step 2, above, for establishing the NPH performance requirements for SSCs. Additional criteria and guidance for Step 2 specific to an NPH type are provided in Sections 3 through 8. These sections also provide criteria and guidance for calculating NPH demands (i.e., Step 3) and for SSC design (i.e., Step 4) for each of the NPH types, specifically:

- 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 Precipitation Hazards (i.e., snow, rain, ice, or their combination); and
- Section 8 addresses Volcanic Eruption Hazards.

The remainder of the standard provides general criteria and guidance applicable to all NPH types.

- Section 9 presents criteria and guidance for modifications of existing facilities and for periodic evaluation of NPH assessments;

[1] Active geological faults are those demonstrating multiple movements within the last approximately 500,000 years, or at least one movement within the last approximately 50,000 years.

- Section 10 provides criteria and guidance for ensuring quality assurance and peer reviews;
- Section 11 provides references; and,
- Appendices A and B provide glossary and acronyms, respectively.

2.0 General Criteria and Guidance for NPH Design

Criteria for NPH design of an SSC are dependent on the NDC of the SSC. This section provides criteria and guidance for selecting NDCs that are appropriate for SSCs from the consideration of their failure consequences to workers and the public. This section also provides criteria and guidance for defining NPH-related SSC failure.

This Standard is written primarily for NPH design of hazard category 1, 2, and 3 nuclear facilities, the criteria and guidance for which are given in Section 2.2, Section 2.1 provides criteria and guidance that are applicable for all other facilities (see Section 1.3 for a list of facilities to which this Standard is applicable).

2.1. Facilities Other than Hazard Category 1, 2, and 3 Nuclear Facilities

2.1.1 For facility risk categorization and design of SSCs subjected to seismic, wind, flood, and precipitation (snow, ice, and rain) loads, the criteria and guidelines given in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, shall be used. For these facilities, lightning protection shall be in accordance with the National Fire Protection Association (NFPA) 780-2011, *Standard for the Installation of Lightning Protection Systems*. Annex L of NFPA 780-2011 provides guidance to determine if a lightning protection system is required. For facilities in which a Faraday cage is selected, Chapter X of DOE-STD-1212-2012, *Explosives Safety,* provides guidance on installation, inspection, and maintenance. Electrical distribution lines, utility connections, piping, and fencing should be protected from current surges by surge protective devices, bonding and grounding. Consideration should be given to providing lightning protection to bus shelters, guard shacks and other structures where personnel may seek shelter. Also, it is recommended that sites within 400 kilometers of a Quaternary volcanic vent (such as the Idaho National Laboratory, the Los Alamos National Laboratory and the Hanford site) consider using Section 8 of this Standard to calculate potential ash loads on roofs and to determine the applicable design load combinations.

2.1.2 Facilities containing explosives, or those that can be affected by detonation (inadvertent or planned) of explosives, are required by the Code of Federal Regulations (C.F.R.) in 10 C.F.R. 851, *Worker Safety and Health Program*, to use Chapters VI and X of the DOE-STD-1212-2012, *Explosives Safety*, in addition to the requirements given in Sections 2.1.1 and 2.1.4 of this Standard. Special care may be needed in detailing frangible (blowout panels) to meet both criteria. Additional care is recommended for the design and securing of industrial, laboratory equipment (with more than de minimus quantities of explosives) and shelving for explosives storage in seismically prone areas to preclude impact to explosives due to shelving collapse, or explosives ejection, or falling.

2.1.3 NPH design of facilities with biological hazards should be based on an NDC level and LS that are consistent with their safety and containment criteria.

2.1.4 To comply with Public Law 102-614 and Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings*, the guidelines provided in the Interagency Committee on Seismic Safety in Construction's (ICSSC) RP-8, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings*, shall be used to:

- determine when a seismic evaluation and retrofitting of an existing non-nuclear facility will be necessary; and

- establish the evaluation and mitigation requirements. Additional guidelines are provided in ICSSC RP-5, *ICSSC Guidance on Implementing Executive Order 12941 on Seismic Safety of Existing Federally Owned or Leased Buildings*.

2.1.5 For facilities with significant chemical or toxicological hazards, the design should consider the guidance and criteria in Section 2.3.9, or equivalent.

2.2 Hazard Categories 1, 2, and 3 Nuclear Facilities

2.2.1 Background and Overview. ANSI/ANS-2.26-2004, *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design*, provides a process for determining a seismic design category (SDC) and LS that establishes performance expectations for SSCs when subjected to seismic (i.e., earthquake-related) hazards. 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 term LS defines SSC failure from seismic loads only, and in this Standard, this term is not applicable to other NPHs. Deformation-related failures resulting from other, non-seismic NPHs are defined by the design codes and criteria that are used to design the SSCs. For NPH design of SSCs in nuclear facilities, subject to the additional and superseding criteria and guidelines provided in this Standard, the intent is to use the radiological hazards evaluation and NPH design categorization process provided in ANSI/ANS-2.26-2004, supplemented by DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facilities Documented Safety Analysis* and DOE-STD-1189-2008. Thus, for various NPHs, the SSCs will be categorized into the following NDC:

- For seismic hazards: SDCs 1 through 5 (i.e., SDC-1 through SDC-5);
- For extreme wind, tornado, and hurricane hazards: wind design categories (WDCs) 1 through 5 (i.e., WDC-1 through WDC-5);
- For flood, seiche, and tsunami, hazards: flood design categories (FDCs) 1 through 5 (i.e., FDC-1 through FDC-5);
- For extreme precipitation hazards: precipitation design categories (PDCs) 1 through 5 (i.e., PDC-1 through PDC-5; and
- For volcanic eruption hazards: volcanic design categories (VDC) 1 through 5 (i.e., VDC-1 through VDC-5).

The remainder of Section 2 provides general criteria and guidance for NPH design categorization and for defining SSC failure conditions. Additional details are provided in each NPH-specific section of this Standard (i.e., Sections 3 through 8).

2.2.2 General Criteria and Guidance for Establishing Various NPH Design Categories

2.2.2.1 For hazard category 1, 2, and 3 nuclear facilities, the NDCs for safety (i.e., safety class and safety significant) SSCs shall be determined based on analysis of the severity of unmitigated consequences using the categorization methodology given in Appendix A of DOE-STD-1189-2008.

2.2.2.2 The NDC of an SSC establishes the target performance goal for the SSC, (same as those specified in ANSI/ANS-2.26-2004 and ASCE 43-05, *Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities*, for seismic hazards), and the return period of the NPH event given in this Standard to which the SSC will need to be designed. For existing facilities, the NDC establishes the return period of the NPH event to which the SSC design will need to be evaluated.

2.2.2.3 The Performance Goal (defined in ANSI/ANS-2.26-2004 in terms of annualized failure probability) and the Return Period of the design or evaluation basis NPH of an SSC, are 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 longer (i.e., the peak ground acceleration will be high) than that for SSCs whose failure does not result in any significant off-site consequences to the public.

2.2.2.4 Consistent with ANSI/ANS-2.26-2004, SSCs shall be given a NDC (i.e., design category 1 through 5) for seismic, wind, flood, precipitation, and volcanic eruption (e.g., ashfall) NPHs. For lightning protection, since available data on the level or the size of lightning events and their return periods are not adequate, SSCs have been placed only into two groups: one for SSCs that may not perform their safety functions when subjected to a lightning event, and, therefore, requires lightning protection; and the other for SSCs that do not require lightning protection.

2.2.2.5 In applying the categorization criteria given in Appendix A of DOE-STD-1189, no higher designations than NPH category 3 design requirements are necessary for co-located 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 needs to remain in the facility for safe shutdown or other safety-related purposes, should NDC 3 be considered for SSCs required for the protection of that worker.

2.3 General Criteria and Guidance for Defining Failure Condition

2.3.1 For different SSCs, the “failure condition” (i.e., condition where the SSC cannot be relied upon to 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 Standard.

2.3.2 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. For other NPHs, dynamic loads, which consider deformation-related SSC failure, the definition of failure shall be consistent with the design codes being used. For example, for wind-related missile hazard design, the SSC failure definition shall be consistent, as specified in this Standard, with that provided in applicable standards such as American Concrete Institute (ACI)-349-06, *Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary*, Appendix F, and ANSI/ American Institute of Steel Construction (AISC) N690-06, *Specification for Safety-Related Steel Structures for Nuclear Facilities*, Section NB-3. However, the hazards consequence evaluation process and radiological dose criteria by which SDCs are determined in ANSI/ANS-2.26-2004 are also applicable for selecting design categories for NPHs other than seismic.

2.3.3 For wind-related hazards evaluations in Section 4 of this Standard, except for evaluating tornado or wind-borne missile impacts, and for other NPH evaluations in Sections 5 through 8 of this Standard, an SSC failure shall be defined, as specified in this Standard, in terms of load combinations, permissible stress, strain, or deformation given, as applicable, in ASCE/SEI 7-10, ACI-349-06 (for NDC 3, 4, and 5 only), or ANSI/AISC N690 (for NDC 3, 4, and 5 only), the provisions of which shall be used in designing the SSCs.

2.3.4 The computed stress, strain, or deformation in the SSC, when subjected to NPHs, shall not exceed the threshold value of any of these parameters at which the SSC fails to perform its safety function. For example, even if the maximum stress and strain in an SSC, when subjected to an NPH event, are within the permissible stress and strain criteria, the SSC deformation shall not exceed 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.

2.3.5 When subjected to certain NPHs, all SSCs may be susceptible to failure, not only because of excessive stress, strain, or deformation, but also due to other modes of failure (as examples: inundation during a flood; electrical malfunction, such as short-circuiting and connection failure; and explosion due to tornado atmospheric pressure change). These failure modes shall also be considered in the hazard evaluation.

2.3.6 In designing an SDC-3, SDC-4, or SDC-5 building structure for a new facility that has a direct confinement safety function, the LS is determined by the design analysis.

2.3.7 For criticality prevention, DOE O 420.1C requires that criticality safety evaluations show that entire processes involving fissionable materials remain subcritical under normal and credible abnormal events, including these initiated by design basis events. Credible design basis NPH events for the purposes of criticality process analysis are those equivalent to NDC-3. The criticality process analysis will identify applicable SSCs relied upon to ensure subcriticality during credible abnormal conditions. NPH Design Category and limit states are assigned depending upon the required safety function. For the purposes of applying ANSI/ANS-2.26-2004 as interpreted by DOE-STD-1189-2008, criticality hazards are treated like any other radiological hazard with the following exception: the SSCs whose safety function establishes single contingency for NPH shall be designed to a NPH Design Category NDC-3 and appropriate limit states (i.e., SSCs whose NPH-initiated failure alone can lead directly to a criticality accident shall be designed to NDC-3 with deformation limits established to prevent the criticality accident). If a process cannot be shown to meet the ANSI/ANS-8.1-1998, *Nuclear Criticality Safety I Operations with Fissionable Materials Outside Reactors*, recommendation for double contingency for NPH events because of NPH induced SSC failure, DOE O 420.1C requires an explanation in the DOE approved Criticality Safety Program for not implementing a recommendation in the applicable ANSI/ANS-8 Standards.

2.3.8 To ensure that proper failure criteria are developed (e.g., for seismic design of an SSC, the 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 all of their potential failure modes:

- Safety Analyst who is responsible for hazard and accident analyses;

- 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

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

2.3.9 Additional Guidance for Hazard Category 1, 2, and 3 Nuclear Facilities with Chemical Hazards. Federal Regulation 10 C.F.R. 830, *Nuclear Safety Management,* and DOE O 420.1C both require evaluation of chemical and toxicological hazards in the design of hazard category 1, 2, and 3 nuclear facilities and protection against these hazards. The NDC for SSCs that provide protection from chemical or toxicological hazards shall be determined based on the unmitigated consequences of SSC failure from an NPH event. The methodology for this categorization should be consistent with DOE-STD-1189-2008 and direction from the responsible program office. The higher of the NDCs determined from the application of radiation dose criteria of Section 2.2.2 and the criteria for chemical dose should be used. The LS should be chosen to be consistent with safety and containment criteria.

3.0 Criteria and Guidelines for Seismic Design

This section 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 LS 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 2-1 of this Standard (i.e., categorization guidance, in terms of unmitigated dose consequences, given in Table 2-1 shall take precedence over those in Table A.3 of ANSI/ANS-2.26-2004).

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

3.1.3 SDC-1 and SDC-2 SSCs having safety functions requiring other LS, shall be designed following ASCE/SEI 7-10 provisions for Risk Category II and Risk Category IV, respectively, except as shown in Table 3-1 of this Standard, which replaces the table in Appendix A.1 of DOE-STD-1189-2008. In Table 3-1, the R values given in ASCE/SEI 7-10 have been modified to account for the difference between the limit states achieved by ASCE/SEI 7-10 and the LS 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.”

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, DBE return periods given in ANSI/ANS-2.26-2004 and ASCE/SEI 43-05, and appropriate Design Factors in 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.

Table 3-1:
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 $R_a = R/1.25$ $R \geq 1.2$	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a = R/1.5$ $R_a \geq 1.2$	ASCE/SEI 7-10, Use Risk Category II, I = 1.0 $R_a \geq 1.0$
2	N/A	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 $R_a = R/1.2$ $R_a \geq 1.2$	ASCE/SEI 7-10, Use Risk Category IV, I = 1.5 $R_a \geq 1.0$

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 between the limit states achieved by ASCE/SEI 7-10 and the LS A, B, C, and D, as defined in ANSI/ANS-2.26-2004 and ASCE/SEI 43-05. ASCE/SEI 43-05, in Table C1-1, recognizes that Seismic Use Group (SG) I, SG II, and SG III of ASCE/SEI 7-02 (i.e., Risk Categories II, III, and IV, respectively, in ASCE/SEI 7-10) are equivalent to SDC-1 LS-A; SDC-1 LS-B; and SDC-2 LS-B, respectively. Also, it recognizes that SG III of ASCE/SEI 7-02 (i.e., Risk Category IV in ASCE 7-2010) is equivalent to SDC-1 LS-C. Thus, the ratio between LS A and B and between B and C are approximately 1.25 and 1.2, respectively. The R_a values given above are based on these ratios.

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), and evaluating surface fault rupture hazards and seismic-induced ground failure hazards, shall be performed following the requirements given in ANSI/ANS-2.27-2008. In addition, the following criteria shall be satisfied:

- 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 percent to the hazard at a site shall be characterized. For DOE purposes, earthquake sources contributing >1 percent to the hazard shall be characterized.

- Table 1 of ANSI/ANS-2.27-2008 column two is labeled “Maximum Considered Earthquake 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.”

- 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:

- 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 CAV in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard Analyses*, may be useful. This guidance may be used if site-specific sensitivity analyses demonstrate that site hazard at return periods of interest is not unduly reduced. In no case shall a lower bound be higher than a 5.5 magnitude; and

- If any of the provisions given in Section 5.4 of ANSI/ANS-2.29-2008, *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. For integrating site response into PSHAs, additional guidance can be obtained from U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.208, *Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*, and NRC's NUREG/CR-6728, *Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines*.

3.4.2 For use in foundation input motions of embedded structures, it is necessary to define the Uniform Hazard Spectrum (UHS) both at bedrock and ground surface outcrop. In addition, to have compatible foundation motions to the UHS, a suite of representative (equally likely) soil profiles should be provided by the PSHA.

3.4.3 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 Sections 11.4.7 and 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 4-98, *Seismic Analysis of Safety-Related Nuclear Structures,* shall be used for determining seismic demands, based on the following considerations and exceptions:

3.5.1.1 Design Basis Seismic Ground Motion. For a new facility, the method of determining the design basis seismic ground motion shall be developed by considering the current state-of-the-art methods, including, but not limited to:

- the requirements of Section 2 of ASCE/SEI 43-05;
- seismic input requirements given in Section 2 of ASCE 4-98, but only to the extent these are consistent with the requirements of Section 2 of ASCE/SEI 43-05; and
- NRC Regulatory Guide 1.208.

3.5.1.2 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 of ASCE 4-98, shall not be used.

3.5.1.3 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.

3.5.1.4 For evaluation of seismic response, the mass and stiffness effects of nonstructural elements of buildings or equipment, even though these elements are not part of the lateral force resisting system, shall be considered.

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 3-1 of this Standard to account for the difference between the limit states achieved by ASCE/SEI 7-10 and the LS 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 to code requirements. The computed D/C value shall not exceed unity.

3.6.4 The following five fundamental principles shall be followed in developing a design to minimize the adverse consequences of earthquake-related hazards. These are as follows:

- Provide a continuous and traceable load path from surface to foundation;
- Ensure that all viable loads and load combinations are accounted for;
- Provide redundant structures or structural elements that can redistribute loads when one structural element is overloaded;
- Provide ductile elements and connections that can undergo deformations beyond yield without sudden and catastrophic collapse; and
- Anchor mechanical equipment on roofs to resist specified wind and missile loads.

3.6.5 Nonstructural elements attached to the structure shall be designed in a manner that allows for seismic deformations of the structure without excessive damage to the structure.

3.6.6 Seismic qualification of equipment may be performed by testing and/or by using actual earthquake experience or generic shake table test data subject to the criteria and limitations given in ASCE 43-05 (see Section 8.3) and DOE/EH-0545.

3.6.7 In designing attachments for the distribution lines (e.g., piping, tubing, conduit, or cables, etc.), sufficient flexibility should be provided between the distribution line support nearest to the anchor point and the anchor point so that the distribution system can withstand the postulated relative displacement during a design basis seismic motion.

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 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 straight-line wind hazards, tornadoes, and hurricanes 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); and,
- Designing SSCs to mitigate the effects of wind-related hazards (Section 4.4).

If a new facility is to be constructed on a site with existing Wind Hazard Analyses, then the Wind Hazard Analysis used for the new facility would need to conform to the requirements of this standard.

WDC-1 and WDC-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 Sections 4.2 through 4.5 of this Standard are only applicable to WDC-3, WDC-4, and WDC-5 SSCs. However, if Federal Emergency Management Agency (FEMA) or International Code Council (ICC) requirements are mandated by the local, city, county, or state regulatory agencies for tornado and hurricane shelters, these also shall be used in conjunction with ASCE/SEI 7-10 requirements and the requirements provided in this Standard.

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, as supplemented in this section. Alternatively, these design parameters may be based on a site-specific PWHA, the development of which shall follow the guidelines and criteria provided in Section 4.3.2 of this Standard.

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, hurricane-induced water surges and hurricane-generated missiles that are applicable to the DOE site and facility.

4.1.2 The failure of the safety function of some SSCs, when subjected to a wind-related hazard, can occur not only because of excessive rupture, instability, deformation or distortion failure modes, but also as a result of intrusion of wind-borne water into, or onto, the SSC. Such wind-borne water intrusion-related failure modes (e.g., shorting or malfunctioning of an electric circuit or of mechanical equipment), typically associated with storm surge flooding caused by sustained high winds on large bodies of water, shall be accounted for in determining SSC unmitigated 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 and Section 7.0 for precipitation hazards.

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

4.1.4 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 wind-borne missile impact may respond inelastically as defined in ACI 349-06 Appendix F and ANSI N690-06 Section NB-3 and considering empirical penetration formulas which demonstrate the target will not be perforated.

4.1.5 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 for straight-line and hurricane wind speed and the criteria of ANSI/ANS-2.3-2011 for tornado wind pressure loads, APC and from tornado missiles.

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, that is 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 (see Section 4.3), 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 anthropogenic 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.

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

4.2.3.1.1 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.

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

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

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

4.2.3.2 Wind Data Collection. Wind data shall be collected to characterize three types of wind-related hazards: 1) straight-line winds; 2) hurricane winds; and 3) tornado winds. 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.

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. Wind data to determine straight-line intensities shall be collected at locations near the site. On-site 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:

- There shall be at least ten continuous years of annual extreme wind speed records. However, if longer periods of record exist, the entire period shall be used.
- 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), shall be identified and the recorded wind speeds shall be corrected using acceptable logarithmic wind height conversion methods.
- The type of wind speed parameter recorded over time shall be specified (e.g., fastest-mile, peak speed, 3-second gust speed, etc.).
- The recorded wind speeds shall be obtained from anemometers located in flat open terrain, if possible.
- It is possible to utilize meteorological data from on-site 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.
- In the absence or lack of sufficient on-site 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:

- Location of hurricane tracks, including information on longitude and latitude, with landfall locations;

- Life-cycle hurricane intensity history, inclusive of Saffir-Simpson scale;
- Reported minimal central barometric pressure near the coast or at point of landfall; and
- 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 in Miami, FL, and the National Climatic Data Center (NCDC) in 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). States in the South Central U.S., especially Oklahoma, Kansas, and 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:

- Tornado track, including latitude and longitude;
- Tornado intensity, using the Enhanced Fujita, or EF, scale;
- Tornado length and width; and
- Data and information necessary for characterizing potential tornado wind-borne missiles (e.g., weight, size, and shape).

Sources of data on tornadoes are available from the National Severe Storms Forecast Center in Norman, OK; National Oceanic and Atmospheric Administration; 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 below. 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: 1) extreme straight-line winds; 2) hurricane winds; and 3) tornado winds.

4.3.2.2 Extreme straight-line winds are non-rotating winds 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 wind-borne missiles (including weight, size, shape, and 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 wind-borne 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 method for developing a site-specific PWHA shall be consistent with the prevailing industry practice and guidelines, including those in Section 3.4 of ANSI/ANS-2.3-2011, and shall use the latest available occurrence data considering the uncertainties therein. The site-specific PWHA shall be performed by a panel consisting of at least three subject matter experts (SMEs). The development of a site-specific PWHA shall be subjected to a peer review.

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 and as indicated in the ANSI/ANS-2.3-2011 wind region maps and tables.

4.3.2.8 The return periods for the tornado winds could be justified to be the same as the extreme straight-line and hurricane wind speeds, but higher return periods have been specified in Table 4-1 for the following reasons:

- the traditional approach for specifying tornado criteria has been to select high return periods, and a precedence for doing this was established in specifying tornado criteria for commercial nuclear power plants;

- the straight-line wind speeds are larger than the tornado wind speeds at lower return periods; and

- the use of higher return periods for tornadoes has been traditionally justified because it provides additional protection against uncertainty without placing undue hardship on the design.

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 Wind**	Tornado Wind*
WDC-3	2,500	2,500	50,000
WDC-4	6,250	6,250	125,000
WDC-5	***	***	***

* 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; or see ANSI/ANS-2.3-2011 for additional information.

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

*** Extreme straight-line wind not evaluated. See NRC R.G. 1.76, Rev. 1, “Design Basis Tornado and Tornado Missiles for Nuclear Power Plants”, 2007 for tornados and NRC R.G. 1.221, “Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants,” October 2011 for hurricanes.

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 below:

4.3.3.1 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.

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

4.3.3.3 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 Any 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 below.

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

4.4.2.1 WDC-3, WDC-4SSCs shall be designed in accordance with the criteria and methodology contained in this Standard and in ANSI/ANS-2.3-2011, employing the methodology given in ASCE/SEI 7-10 to withstand the applicable design basis wind, and APC.

4.4.2.2 In designing the SSCs to withstand the design basis tornado winds, ASCE/SEI 7-10 methodology for determining straight-line wind loads shall be used, except as specified below:

4.4.2.2.1 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 the 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 can also be determined assuming Exposure Category C.

4.4.2.2.2 For designing SSCs against extreme straight-line wind, hurricane wind, and tornado wind loads, the following load combinations shall be used for the extreme loads using strength design:

$D + F + 0.8(L + L_r) + W$

$0.9D + F + W$

$0.9D + W$

where,

D = dead load, F = loads due to normal flood, L = live load, L_r = roof live load, and W = extreme straight-line wind, hurricane wind, or tornado windload, including APC, 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 of ANSI/ANS-2.3-2011.

4.4.2.3.1 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 determining wind pressure loads, but appropriately considering the impaction nature of the load, including the deformation characteristics of the missiles.

4.4.2.3.2 For design of barriers to protect such safety-related SSCs against tornado APC or tornado and hurricane missile impact loads, a permissible state of deformation of the barrier beyond yield may be used to calculate the barrier capacity as defined in ACI-349-06 Appendix F or ANSI N690-06 Section NB-3. 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. Additional guidance can be obtained for barrier evaluation from the following references:

- *Report of the ASCE Committee on Impactive and Impulsive Loads,* Volume V, Civil Engineering and Nuclear Power, American Society of Civil Engineers, September, 1980;

- *Structural Analysis and Design of Nuclear Plant Facilities,* Manuals and reports on Engineering Practice, No. 58, American Society of Civil Engineers,1980;

- *A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects* by Robert Kennedy, Nuclear Engineering and Design, Volume 37, North Holland Publishing Company, 1976; and

- *Structures, Systems, and Components Evaluation Technical Support Document for the DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities. UCRL-ID-123577. Lawrence Livermore*

National Laboratory, 1996 (Technical Support Document to DOE-STD-3014).

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 1,000 cubic feet of volume are present, or if openings of this size can be caused by missile perforation, the effects of internal pressure should be considered according to the applicable methodology in ASCE/SEI 7-10.

4.4.2.5 If a structure is sealed, 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 rotational 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 for a sealed building shall be one-half the maximum APC pressure combined with the maximum tornado wind pressure, or one-half wind pressure and maximum APC, whichever controls design.

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 ensure 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 for all WDC levels. These are as follows:

- Provide a continuous and traceable load path from surface to foundation;
- Ensure that all viable loads and load combinations are accounted for;
- Provide redundant structures or structural elements that can redistribute loads when one structural element is overloaded;
- Provide ductile elements and connections that can undergo deformations beyond yield without sudden and catastrophic collapse;
- Provide missile-resistant walls and roof elements;
- Anchor mechanical equipment on roofs to resist specified wind and missile loads; and
- Minimize or eliminate the potential for wind-borne missiles.

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:

- Determining an FDC of an SSC, based on the severity of SSC failure consequence. (Section 5.1);
- Performing a site flood characterization and characterizing site hydrology and hydrological data (Section 5.2);
- Determination of flood design parameters (Section 5.3);
- 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
- Designing SSCs to mitigate the effects of flood-related hazards (Section 5.5).

If a new facility is to be constructed on a site with existing Flood Hazard Analyses, then the Flood Hazard Analysis used for the new facility would need to conform to the requirements of this Standard.

Hazards from localized flooding resulting from extreme precipitation (i.e., snow, rain, or ice), and the design of site drainage systems to mitigate these hazards are addressed in Section 7.

For facilities with only FDC-1 and FDC-2 SSCs, the provisions in Sections 5.2 and 5.3 shall be mandatory only to the extent these are necessary to define DBFL in accordance with Section 5.4.1.2.

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 of this Standard.

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

5.1.2 The failure of the 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 mechanical 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 waters shall also be considered in determining unmitigated failure consequences.

5.1.4 For a facility in a flood-prone area which has SSCs of FDC-3 or higher, dikes, barriers, and/or enclosures shall be built for providing flood protection to the SSCs. These dikes, barriers, and enclosures shall be placed in an FDC equal to the category of the SSC or SSCs 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. Section 5.5.4.1 provides design criteria for protective SSCs.

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 Off-site 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.

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-3009-94).

5.2.1.3 A topographic map shall 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.

5.2.1.4 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.

5.2.1.5 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.

5.2.1.6 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.

5.2.1.7 The site flood characterization shall be performed by 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.

5.2.1.8 Guidelines and requirements for collecting flood-related hazard data that are necessary for conducting site-specific PFHA are provided below.

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 Sections 5.3.1 through 5.3.13.

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

- Initial data requirements shall focus on the need to identify potential sources of hydrologic flood-related hazards to the site.
- For each specific hydrologic flood-related hazard, a summary of hazard characteristics shall be provided.
- The worst case flood-related hazard shall be summarized, and only the worst case flood hazard needs to be summarized in detail.
- 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 they 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:

- Walkdown of site and vicinity;
- Site-specific and regional topographic maps;
- Aerial photographs of the site and vicinity;
- Hydrologic data (i.e., stream gauge data);
- Historical flood event reports;
- FEMA flood insurance studies; and
- 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., the COE, the U.S. Bureau of Reclamation, the USGS, the FIA, the Department of Water Resources, Agricultural Department, the NWS, the TVA, 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.

5.3. Determination of Flood Design Parameters for Flood-Related Hazards

Table 5-1 identifies 13 flood-related hazards and the natural and anthropogenic phenomena causing them. The following 13 sections (Sections 5.3.1 through 5.3.13) provide criteria needed to define site specific information for each flood-related hazard.

Table 5-1:
Flood-Related Hazards

Flood-Related Hazard	Natural and Anthropogenic 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:

- Location and elevation of the rivers at the location nearest the site;
- Historical records of stream flow data (i.e., maximum yearly peak discharge and stage elevation) with recording location;
- Maximum flood level that may be expected from a combination of the most critical historical meteorological and hydrologic conditions;
- 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

- 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:

- Characteristics of the watershed basins of the river; and
- 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:

- Name of dam;
- Owner of dam;
- Type of dam (e.g., earth fill, concrete, etc.);
- Date of dam completion;
- River name and location (e.g., river mile);
- Total height of dam;
- Capacity of dam; and
- 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:

- Results of seismic hazard analysis;
- Data necessary to perform upstream river flooding hazard analysis;
- Data on dam and dam characteristics necessary to evaluate its resistance to the seismic loads and overtopping, including:
  - Material properties of the dam and abutment; and
  - Characteristics of gates and other mechanical equipment which could affect the dam performance.
- Reservoir depth, length and storage elevation tables;
- Manning's roughness coefficient, and top-width elevation tables for downstream cross sections;
- In the case of overtopping events, the depth of overtopping at which failure occurs;
- In the case of hydrologic events, an inflow hydrograph; and
- 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:

- Bathymetric characteristics of the coastline (i.e., depth tables);
- Tide levels; and
- 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 If the potential for a landslide hazard exists, 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, thereby creating 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., the states of Idaho and 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.

5.3.10.2 Over 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 to the SSCs from the force of the debris.

5.3.12.2 For sites located in areas where damage from water-borne 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 anthropogenic SFE activities (i.e., the process of separating one component - the extractant - from another - 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 International Building Code (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 determining DBFL for various FDCs of SSCs shall be as provided in Table 5-2A. Design basis flood structural loads in SSCs shall be based on return periods as provided in Table 5-2B. The reason the return periods are higher in Table 5-2A is because these are applicable to those SSCs that are assumed to fail unconditionally due to submergence or water intrusion. For these SSCs, it is not possible to provide margin in the flood design of an SSC for the flood levels from stream/river flooding (i.e., the SSCs are either above the flood level or they are not). For these SSCs, the annual probability of functional failure is the same as the annual probability of hazard occurrence. But, structural components that do not fail unconditionally due to submergence or water intrusion, when designed following design codes, because of built-in structural design conservatism, the design basis annual probability of hazard occurrence can be more (i.e., lower return period) to achieve the same target annual probability of SSC functional failure. Therefore, the return periods in

Table 5-2A shall be used to determine DBFL's for establishing building elevations, heights of protective barriers, heights of waterproofing, etc. The lower return periods in Table 5-2B (the same as those for extreme wind loads) shall be used to determine design basis flood loads on building structural walls, protective barriers, etc.

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 5-2A:
Return Period for Design Basis Flood Level (DBFL) for Various Flood Design Categories

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

Table 5-2B:
Return Period (Years) for Design Basis Flood Structural Loads

SSC Category	FDC-1	FDC-2	FDC-3	FDC-4	FDC-5
Return Period (Years)	100	200	2,500	6,250	10,000

5.4.2 Determination of DBFL for Facilities with FDC-3, FDC-4, and FDC-5 SSCs. For sites and facilities with FDC-3, FDC-4, and FDC-5 SSCs, a site-specific PFHA shall involve the following two steps:

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

- 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 (FSA). The objective of an 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:

5.4.2.1.1 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.

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

- River/stream flooding;
- Dam, dike, or levee failure;
- Local precipitation (i.e., rainfall, ice melt, and snow melt, see also Section 7); and
- Storm surge, seiche, and tsunami.

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

5.4.2.1.2 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).

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

For sites that cannot be clearly demonstrated to be a flood-dry site, perform a preliminary PFHA following the guidelines given below, and determine if a CFHA is necessary:

- Compile, obtain and update a data base of peak discharges for streams/rivers;
- 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 in UCRL-21069, *Preliminary Flood Hazard Estimates for Screening Models for Department of Energy Sites*;
- Determine the stage-discharge relationship (a relationship between flow discharge and flood stage); and
- Transform the probability-discharge frequency to stage frequency to determine the probability of exceeding selected stage elevations using the stage-discharge relationship.

5.4.2.2 Comprehensive Flood Hazard Assessment (CFHA). 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.

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

5.4.2.2.2 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.

5.4.2.2.3 CFHA considerations should include the following:

- Estimation of rainfall and snowfall frequency in watersheds;
- Overland flow assessment due to precipitation;
- Hydrologic modeling of watershed responses using verified and validated models;
- Assessment of discharge (i.e., flow rates) and flood elevations using detailed hydraulic modeling techniques;
- Estimation of joint natural hazard events frequency (e.g., joint probability analysis shall be performed to assess surge level frequencies;
- Assessment of likelihood of upstream dams and levees failure where all causes of dam failure shall be accounted for; and
- 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.

5.4.2.2.4 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.

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

- Stochastic methods;
- Probabilistic hydrologic modeling (e.g., Bayesian analysis, joint probability methods, etc.); and
- Paleohydrological analysis (i.e., evaluating ancient evidence using age-dating techniques to deduce early extreme hydrologic events).

5.4.2.2.6 Causes of dam failure to be evaluated include:

- Hydrologic, seismic, hydrostatic, operations-related error;
- Random structural failure;
- Upstream dams; and
- Landslides.

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

5.4.2.2.8 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.

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

5.4.2.2.10 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.

5.4.2.2.11 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.

5.4.2.2.12 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 an 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 the event combination cases as shown in Table 5-3. 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. This section 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 9.4.

5.5.1.3 The hazard annual probability levels in Tables 5-2A and 5-2B correspond to the mean hazard.

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

- Determination of the DBFL for each flood-related hazard, as defined by the hazard annual probability of exceedance and applicable combinations of flood hazards;
- Development of a flood design strategy for the DBFL that satisfies the design requirements (e.g., build above the DBFL, harden the facility, etc.); and
- Design of civil engineering systems (e.g., buildings, buried structures, site drainage, retaining walls, dike slopes, etc.) to the applicable DBFL and design requirements.

5.5.1.5 For FDC-3, FDC-4, and FDC-5 SSCs, design basis flood loads (F_a) resulting from flood hazards for return periods shown in Tables 5-2A and 5-2B shall be considered as an Extreme Load category, thus the following strength load combinations shall be used:

$D + 0.8(L + L_r) + W + F_a$,

$0.9D + W + F_a$, and

$0.9D + F_a$,

Where,

D = dead load; S = snow load (normal); L = live load; W = wind load (normal); F_a, = hydrostatic and hydrodynamic (including wave and impact) loads resulting from the FDC-specific design basis flood hazard (DBFH). Note that, the Dynamic Pressure Coefficient, C_p (for wave loads, see Section 5.4.4 of ASCE/SEI 7-10) and Importance Coefficient, C_I (for impact loads from debris, ice, etc., see Section 5.4.5 of ASCE/SEI 7-10) appropriate for the DBFH can be used, if considered applicable, and these coefficients shall not be less those for ASCE/SEI 7-10 Risk Category IV SSCs.

5.5.1.6 The design of FDC-1, and FDC-2 SSCs, shall meet both of the following requirements:

- F_a resulting from flood hazards shall be based on requirements given in Section 5.4.1.2, above; and

- F_a for FDC-1 and FDC-2 SSCs resulting from flood hazards shall be based on ASCE/SEI 7-10 requirements for Risk Category II and Risk Category IV SSCs, respectively.

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 (see Section 7).

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

- 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

- 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 5-3 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).

5.5.2.10 The DBFL is determined by entering the flood-related hazard curve that includes the combination of events provided in Table 5-3 (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 5-3:
Design Basis Flood Event Combinations

Primary Hazard	Case No.	Event Combinations*
River Flooding	1	Peak flood elevation due to all flooding contributors with the exception of upstream dam failure. 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 (i.e., Case 1, above) or as determined in a probabilistic analysis that considers the joint occurrence of river flooding and wind-generated waves.
	3	Ice or debris forces (i.e., static and dynamic) and Case 1.
	4	Peak and ground water level and Case 1 Evaluate the potential for erosion, debris, etc. due to the primary hazard.
Levee/Dam Failure	1	Peak flood elevation due to all modes of levee or dam failure (e.g., overtopping, seismically – or landslide-induced structural failure, upstream dam failure, failure due to ice or debris forces (i.e., static and dynamic), etc.).
	2	Wind-waves corresponding, as a minimum, to the 2-year wind acting in the most favorable direction coincident with the peak flood (i.e., Case 1, above) 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. Should be evaluated as part of the hazard analysis if overtopping and/or failure occur.
Extreme Local Precipitation	1	Peak flood based on runoff analysis due to extreme precipitation (i.e., rain, snow melting, ice melting). Flooding based on the site runoff analysis shall be used to evaluate the site drainage system and flood loads on individual facilities (see Section 7).
	2	Ponding on the roof to a maximum depth corresponding to the level of the secondary drainage system (see Section 7).

Primary Hazard	Case No.	Event Combinations*
Storm Surge, Seiche (due to Hurricane, Seiche, Squall Lines, etc.)	1	Peak flood levels plus mean high tide levels Tide effects corresponding to the mean high tide above the mean low water (MLW) level, if not included in the hazard analysis.
	2	Surge-associated waves and Case 1 Wave action should include static and dynamic effects and potential for erosion.
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.

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 (see Section 7).

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 an SSC or interrupt operations (see Section 7).

5.5.3.6 To perform the flood evaluation for an 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:

a) Determine the SSC FDC;

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

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

d) 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;

e) Develop a design strategy to mitigate flood hazards that impact the SSC. Options include hardening the SSC and modifying the flood path to provide for occupant safety and to secure vulnerable areas;

f) If the SSC is located below the DBFL level even if the SSC has been hardened, 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;

g) Following the provisions given in Section 7, develop an initial site-drainage system and roof-system drainage plan and structural design;

h) Following the provisions given in Section 7, perform a hydrologic analysis for the site to evaluate the performance of the site storm water management system considering roof drainage, anthropogenic, and natural watercourses for the DBFL local precipitation for each SSC;

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

j) For SSCs where flooding occurs, assess whether the SSC performance is satisfactory;

k) 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;

l) Following provisions given in Section 7, 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;

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

n) If the DBFL for an 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; and

o) For SSCs that are impacted by the DBFL, 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.

5.5.3.10 In 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.

5.5.4 Flood Design Strategies

5.5.4.1 All SSCs that are vulnerable to failure due to water intrusion or submergence from flood shall be constructed or placed above the DBFL. If an SSC that is vulnerable to failure due to water intrusion or submergence cannot be placed above DBFL due to cost or other practical considerations, it shall be protected by engineered features that shall be designed to prevent water intrusion resulting from a DBFL that corresponds to the FDC of the SSC that requires protection. The design of the protective features shall be based on the requirements in the NRC Standard Review Plan 2.4.10, *Flooding Protection Requirements,* NRC Standard Review Plan 2.5.5, *Stability of Slopes*, NRC Standard Review Plan 3.4.2, *Analysis Procedures,* NRC Regulatory Guide 1.102, *Flood Protection for Nuclear Power Plants,* and ANSI/ASCE 1-82, N-725 *Guideline for Design and Analysis of Nuclear Safety Related Earth Structures*. All SSCs, including those that are not vulnerable to failure due to water intrusion or submergence, shall be designed to withstand the hydrostatic and hydrodynamic loads resulting from a design basis flood, including those resulting from possible raised ground water level.

5.5.4.2 Flood hazards resulting from local precipitation that shall be considered in the design of the site storm water management system, roof systems, etc., are addressed in Section 7.

5.5.4.3 Since it may not always be possible to construct all SSCs above the DBFL, alternate design strategies shall be considered. The hierarchy of flood design strategies is as follows:

1) Situate the SSC above the DBFL;

2) Reduce the design basis flood hazard;

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

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

5.5.4.4 If an SSC is placed above the DBFL, it is considered to be readily protected from flood hazards.

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 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 on-site, modification of stream channels, etc.

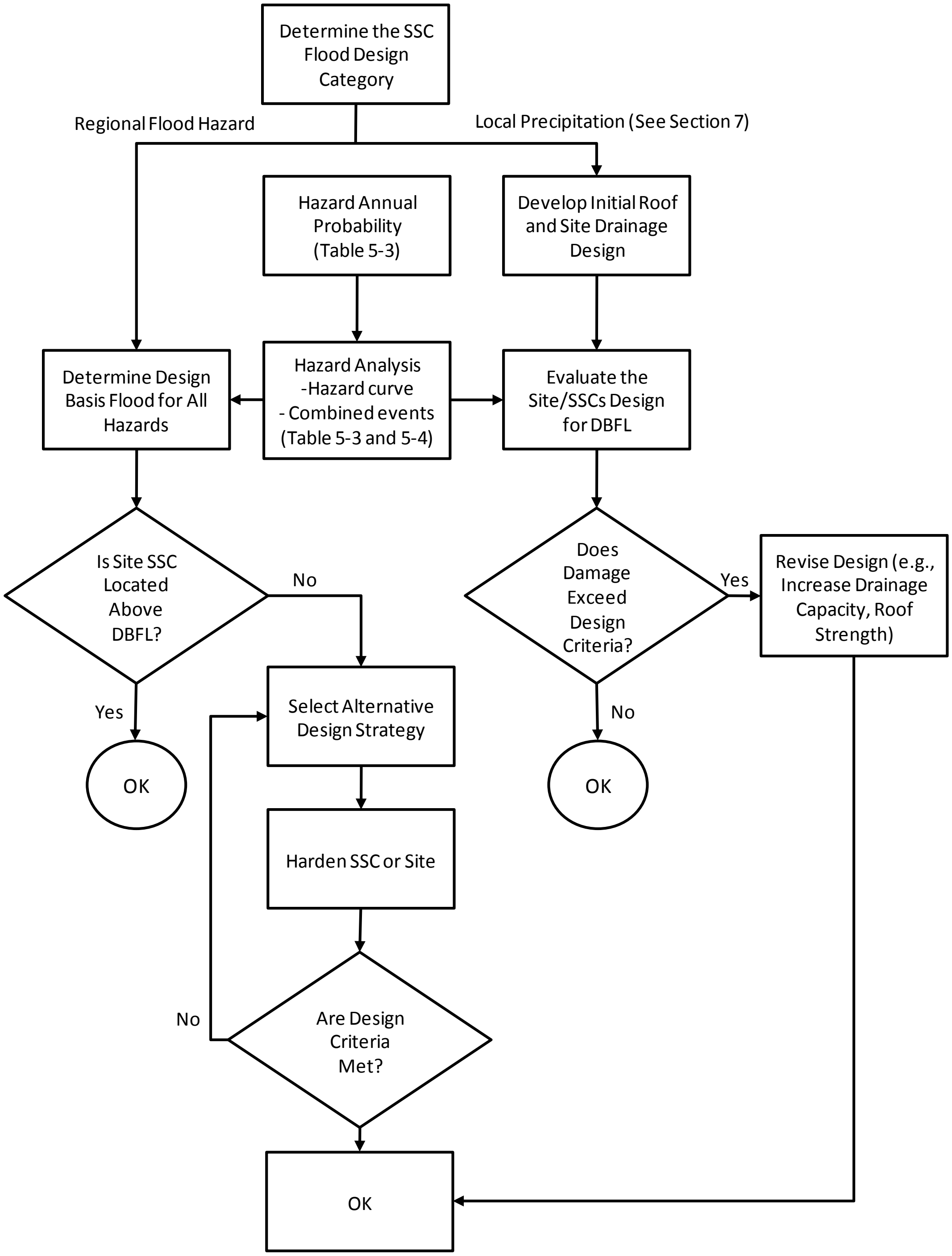

Figure 5-1: Flood Evaluation Process

5.5.4.7 The strategy of hardening an SSC 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 an SSC may be impacted by the DBFL and thus shall be hardened, the designer shall determine the flood loads associated with the DBFL.

5.5.4.8 The design of flood mitigation systems (i.e., exterior walls, flood-proof doors, etc.) shall be conducted in accordance with the requirements specified in Section 5.5.4.1.

5.5.5 Flood-Related Hazard Design Criteria. Unlike design strategies for seismic-related and wind-related hazards, it is not always possible to provide margin in the flood design of an SSC that is vulnerable to failure due to water intrusion or submergence. For example, the simple fact that a site is inundated, even if structural damage does not occur, causes significant disruption (e.g., down time during the flood, clean-up, etc.). This is often unacceptable in terms of the economic impact and disruption of the mission-dependent function of the site. Accordingly, such SSCs shall be kept above the DBFL to ensure that its safety functions are not interrupted. If mitigation systems, such as watertight doors, sealants, etc., are used, they should be designed in accordance with Section 5.5.4.1.

5.5.5.1 Design of FDC-1 SSCs

5.5.5.1.1 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 the return periods as given in Tables 5-2A and 5-2B of this Standard. Event combinations that shall be considered are listed in Table 5-3.

5.5.5.1.2 The occupants' 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).

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

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

- 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
- Developing 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

5.5.5.2.1 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 the return periods as given in Tables 5-2A and 5-2B. Event combinations that shall be considered are listed in Table 5-3.

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

5.5.5.2.3 Procedures 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.

5.5.5.3 Design of FDC-3 SSCs

5.5.5.3.1 FDC-3 SSCs shall be designed using the NRC requirements identified in Section 5.5.4.1, except that the DBFL shall be based on the return periods given in Tables 5-2A and 5-2B. Event combinations that shall be considered are listed in Table 5-3.

5.5.5.3.2 If the design objective is continued function of the facility, including confinement of hazardous materials and occupant safety, FDC-3 SSCs shall be located above the DBFL, if possible, as enumerated in Section 5.5.4.1 above.

5.5.5.3.3 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.

5.5.5.3.4 For SSCs that may be impacted by the DBFL, plans shall be developed to evacuate non-essential personnel, 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.

5.5.5.3.5 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.

5.5.5.3.6 The use of 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

5.5.5.4.1 FDC-4 SSCs shall be designed using the NRC requirements identified in Section 5.5.4.1, except that the DBFL shall be based on the return periods given in Tables 5-2A and 5-2B. Event combinations that shall be considered are listed in Table 5-3.

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

5.5.5.5 Design of FDC-5 SSCs. FDC-5 SSCs shall be designed using the NRC requirements for commercial nuclear power plants.

5.5.6 Flood Design Practice for SSCs below the DBFL Elevation

5.5.6.1 For SSCs located below the DBFL elevation, mitigation measures shall be designed such that the SSCs meet the structural requirements given in Section 5.5.4.1.

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

5.5.6.3 To evaluate the effects of flood hazards, corresponding forces on structures shall be evaluated considering the event combinations given in Table 5-3.

5.5.7 Flood Protection. 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:

- Structural barriers (e.g., exterior building walls, floodwalls, watertight doors);
- Wet or dry flood proofing (e.g., waterproofing exterior walls, watertight doors);
- Levees, dikes, seawalls, revetments; and,
- Diversion dams and retention basins.

The design of structural systems (i.e., exterior building walls) shall be developed in accordance with the requirements in Section 5.5.4.1.

6.0 Criteria and Guidelines for Lightning Design

6.1. SSC Categorization for Lightning Hazards

For designing new facilities, while performing the safety and hazard evaluation, the results of which would be used to determine the seismic and other NDC 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 listed. The Design Basis of these SSCs shall include the requirement for lightning protection.

In addition to providing lightning protection to the above-identified SSCs, in lightning prone areas, consideration should be given to providing lightning protection for bus shelters, stations, or other structures where personnel may seek shelter from the weather. Annex L of NFPA 780-2011 provides guidance in making this determination.

6.2. Designing SSCs for Lightning Protection

6.2.1 SSCs identified in Section 6.1, above, shall be designed to preclude adverse consequences from lightning hazards, and/or shall be protected in accordance with NFPA 780-2011. Other risks to SSCs from lightning may be current surges through electrical distribution lines, utility connections, piping and fencing that can be protected by surge protective devices, bonding, and grounding.

6.2.2 When lightning protection is required for an SSC, a lightning protection system shall be installed and maintained in accordance with NFPA 780-2011. When a Faraday Shield is employed, the lightning protection system shall be installed and maintained in accordance with DOE-STD-1212-2012.

7.0 Criteria and Guidelines for Precipitation Design

This section provides criteria and guidelines for design and evaluation of SSCs for mitigating precipitation due to rainfall, snow, and ice. It provides guidance for:

- Determining the PDC of an SSC based on the severity of SSC failure consequence (Section 7.1);
- Performing a site precipitation characterization and characterizing the hydrological and meteorological data (Section 7.2);
- Determination of precipitation design parameters (Section 7.3);
- Performing Probabilistic Precipitation Hazard Assessments (PPHAs) on the basis of which design parameters are related to the precipitation hazard (Section 7.4); and
- Designing SSCs to mitigate the effects of precipitation hazards (Section 7.5).

If a new facility is to be constructed on a site with existing Precipitation Hazard Analyses, then the Precipitation Hazard Analysis used for the new facility would need to conform to the requirements of this Standard.

The precipitation due to rainfall, snow, and ice can result in local site flooding due to site runoff from the precipitation, can result in hydrostatic and hydrodynamic pressures on dikes or barriers used to protect SSCs from the runoff flooding, and can result in roof loadings on the site structures. The site flooding due to runoff of the precipitation should be integrated with the flood hazards studies discussed in Section 5.0.

7.1. SSC Categorization for Precipitation Design

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

7.1.1 Precipitation design categorization shall be based on the severity of unmitigated failure consequences resulting from all precipitation-related hazards (e.g., rainfall or snowfall site runoff, roof ponding, etc.) applicable to the DOE site and facility.

7.1.2 The failure of the safety function of some SSCs, when subjected to a precipitation-related hazard, can occur not only because of excessive deformation or distortion (e.g., roof loading), but also as a result of inundation of the SSC or intrusion of precipitation water runoff into or onto the SSC. In selecting an SSC PDC 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.

7.1.3 Barriers, enclosures, dikes, and other SSCs, that are provided for precipitation protection of SSCs, with safety functions, shall be placed in a PDC equal to the SSC to be protected.

7.1.4 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 following the requirements in Section 5.5.4.1.

7.1.5 For a large site with varying topography, the precipitation runoff levels may vary from facility to facility.

7.2. Site Characterization for Precipitation Design

7.2.1 General Requirements. The description of general requirements shall, at a minimum, include the following:

7.2.1.1 Precipitation, hydrologic characteristics, and meteorological characteristics of a site and its surroundings shall be investigated in sufficient scope and detail to obtain the data necessary for performing a PPHA.

7.2.1.2 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.

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

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

7.2.1.5 The characterization of the site precipitation shall be performed by 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.

7.2.2 Site Characterization for Precipitation

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

7.2.2.2 For sites where no up-to-date site-specific PPHA has been performed, characterization of local site flooding from precipitation runoff shall be performed in accordance with the guidelines and requirements given in Sections 7.3.1.

7.2.2.3 Precipitation data provided in flood insurance studies by FEMA, and site-specific hydrological studies performed by DOE, including DOE-sponsored contractors, and other governmental agencies (e.g., the COE, the U.S. Bureau of Reclamation, the USGS, the FIA, the Department of Water Resources, the Agricultural Department, the NWS, the TVA, etc.) may be used.

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

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

7.2.2.6 Meteorological events that are potential sources of precipitation for the site shall be determined.

7.2.2.7 Topographic data, storm drainage data, and building location data for the site shall be collected and reviewed to determine the applicable watershed areas to be used for evaluating the runoff flooding that can occur on the site.

7.2.2.8 New safety-related structures shall not be built in areas where flooding from site precipitation can occur unless flood mitigation measures are provided.

7.3. Determination of Precipitation Design Parameters

The precipitation hazards are site flooding from precipitation and building roof loading from rainfall, snow and ice. The following subsections provide guidance on determination of the precipitation design parameters for each of the precipitation hazards.

7.3.1 Site Flooding Precipitation

7.3.1.1 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.

7.3.1.2 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.

7.3.1.3 Site storm water drainage information and information on any site-located dams, levees, dikes, etc. shall be collected.

7.3.1.4 Precipitation (rainfall, snow and ice) data shall be collected. See Section 4.2.3 for guidance on meteorological data collection.

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

7.3.1.6 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.

7.3.1.7 Site flood studies shall be integrated with the river/stream flood studies discussed in Section 5.0.

7.3.2 Building Roof Loading

7.3.2.1 Intense rainfall may create roof ponding when there are flat roofs with roof parapets and the roof drainage system is blocked or its drainage capacity is exceeded.

7.3.2.2 Building roof information (areas, slopes, parapets, roof drainage systems, roof live load design information, etc.) shall be collected to determine roofs which shall require evaluation.

7.4. Probabilistic Precipitation Hazard Assessment and Determination of Precipitation Design Parameters

7.4.1 Determination of the Design Basis Precipitation Level for PDC-1 and PDC-2 SSCs. For sites and facilities with only PDC-1 and PDC-2 SSCs, the design basis precipitation level (DBPL) shall be determined on the basis of the requirements in ASCE/SEI 7-10.

7.4.2 Determination of the Design Basis Precipitation Level for PDC-3, PDC-4, and PDC-5 SSCs

7.4.2.1 For sites and facilities with PDC-3, PDC-4, and PDC-5 SSCs, the results of the PPHA shall be presented in the form of a precipitation-related hazard curve (rainfall, snow, and ice) showing the relationship between precipitation level and the design basis return period in years. For site flooding from precipitation, the results should be presented in the form of a flood-related hazard curve showing the relationship between the flood level and the design basis return period in years.

7.4.2.2 Return periods for the design basis precipitation for various design categories of SSCs shall be as provided in Table 7-1 or Table 7-2. Table 7-1 shall be used when evaluating the flooding caused by runoff of the site precipitation. Table 7-2 shall be used when evaluating structures for the effects of loads resulting from precipitation, i.e. roof loadings, loads on dikes/protective structures, etc,. The reason the return periods are higher in Table 7-1 is because it is not possible to provide margin in the flood design of an SSC for the flood levels from site precipitation runoff, i.e., the SSC is either above the flood level or not. For example, the simple fact that a site is inundated (even if structural damage does not occur), will cause significant disruption (e.g., down time during the flood, clean-up, flooding of safety-related equipment). This is often unacceptable in terms of consequences, 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. For defining the structural loads resulting from precipitation, smaller return periods shall be used, as defined in Table 7-2, because the design process does provide margin in the structural design.

7.4.2.3 For winter precipitation loads (rain, snow, and/or ice), the NRC requirements in NUREG-0800, Subsection 2.3.1, R-3, shall be used to determine the extreme structural loads for PDC-3, PDC-4, and PDC-5 SSCs. The NRC requirements state the extreme winter precipitation loads should be based on the weight of the 100-year snowpack at ground level, plus the weight of the 48-hour probable maximum winter precipitation (PMWP) at ground level for the month corresponding to the selected snowpack. Depending on the location of the site, the 48-hour PMWP may not necessarily be in the form of frozen participation.

Table 7-1:
Return Period (Years) for Design Precipitation Flooding Caused by Precipitation Runoff

SSC Category	PDC-3	PDC-4	PDC-5
Return Period (Years)	10,000	25,000	*

* Use return periods the same as those used by the NRC for commercial nuclear power plant design

Table 7-2:
Return Period (Years) for Design Precipitation Structural Loads

SSC Category	PDC-3	PDC-4	PDC-5
Return Period (Years)	2,500	6,250	*

* Use return periods the same as those used by the NRC for commercial nuclear power plant design

7.5. SSC Design and Evaluation to Mitigate Precipitation-Related Hazards

7.5.1 General Precipitation Design Overview

7.5.1.1 This subsection presents the design guidelines and criteria for mitigating the precipitation-related hazards, and also presents alternative design strategies for mitigating precipitation hazards.

7.5.1.2 Guidance is also provided to evaluate SSCs in existing facilities that may not be located above the DBFL.

7.5.1.3 Evaluation of the precipitation design basis for SSCs consists of the following determinations and evaluations:

- Determination of the DBPL for each precipitation-related hazard as defined by the hazard return periods as applicable;
- Evaluation of the site storm water management system (e.g., site runoff and drainage, roof drainage);
- Development of a precipitation design strategy for the DBPL that satisfies the design requirements (e.g., build above the DBPL, harden the facility, eliminate roof parapets, develop emergency operations procedures); and
- Design of civil engineering systems (e.g., buildings, buried structures, site drainage, retaining walls, dike slopes) to the applicable DBPL and design requirements.

7.5.2 Precipitation Evaluation Process

7.5.2.1 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.

7.5.2.2 For new construction, the preferred design practice is to construct the SSC above the DBPL flood, and design the roofs for the DBPL loads. Live loads on roofs are typically used to design roofs. This design live load may exceed the DBPL loads, thus mitigating the DBPL loads. The magnitude of the design live loads should be considered in determining the rigor of the PPHA that should be done.

7.5.2.3 Evaluate or develop an initial site-drainage system and roof-system drainage plan and structural design per applicable regulations.

7.5.2.4 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.

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

7.5.2.6 If the DBPL for an SSC due to local precipitation produces unacceptable levels of flooding, design modifications shall be developed or mitigation measures shall be developed. The design modifications shall provide for additional capacity (i.e., runoff capacity, additional strength) to mitigate the damage level.

7.5.2.7 For SSCs that are impacted by the DBPL, mitigation measures such as emergency operation plans can be developed to ensure the life safety of personnel and to secure critical areas.

7.5.3 Precipitation Design Strategies

7.5.3.1 The basic design strategy for an SSC is to construct the SSC above the DBPL. When this can be done, local site precipitation-related flood hazards do not have to be considered in the design basis, except that possible raised ground water level shall be considered.

7.5.3.2 Since it may not always be possible to construct a new SSC above the DBPL level, alternate design strategies shall be considered. The following lists the hierarchy of local site precipitation related flood design strategies:

- Situate the SSC above the DBPL level;
- Harden the site or SSC to mitigate the effects of the DBPL such that the SSC is protected; and
- Mitigate the hazards with emergency operation plans to safely evacuate employees and secure areas with hazardous, mission-dependent, or valuable materials.

7.5.3.3 Under certain circumstances the hazard that results from the design basis precipitation 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 on-site, modification of stream channels, etc.

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

7.5.3.5 The design of flood mitigation systems (i.e., exterior walls, flood-proof doors, etc.) shall be conducted in accordance with the requirements specified in Section 5.5.4.1.

7.5.3.6 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.

- All sites shall be designed for the effects of local precipitation; and

- 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.

7.5.3.7 For PDC-3, PDC-4, and PDC-5 SSCs, the site storm water management system design clearly will 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, and the resulting DBPL shall be determined without consideration of the storm sewers.

7.5.3.8 The actual impact of the DBPL precipitation on the SSC shall be assessed by conducting a hydrologic evaluation for the site that accounts for natural and anthropogenic 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, it may be concluded that the design of the site-drainage system (i.e., for the 25-year rainfall) is adequate.

7.5.3.9 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.

7.5.4 Precipitation-Related Design Criteria

7.5.4.1 Design of PDC-1 and PDC-2 SSCs. PDC-1 and PDC-2 SSCs shall be designed using criteria given in ASCE/SEI 7-10 for Risk Category II and Risk Category IV respectively with the applicable Importance Factor.

7.5.4.2 Design of PDC-3, PDC-4, and PDC-5 SSCs. PDC-3, PDC-4 and PDC-5 SSCs shall be designed for the DBPL based on return periods as required in Table 7-1 and Table 7-2. The building structural system shall be capable of withstanding the forces associated with the DBPL or appropriate mitigation actions taken to address the DBPL.

7.5.4.2.1 The following load combinations shall be used for the DBPL flood extreme participation loads on walls, dikes, protective structures, etc:

$D + 0.8(L + L_r) + W_n + F_a$

$0.9D + W_n + F_a$

$0.9D + F_a$

where D is the dead load

L is the live load

L_r is the roof live load

W_n is the normal wind

F_a is the extreme flood load on the walls, etc. considering the static, hydrodynamic, and wave action as appropriate. The flood loads shall be determined using the requirements in Section 5.5.4.1.

7.5.4.2.2 The following load combinations shall be used for the extreme participation defined for the DBPL structural roof loads:

$D + 0.8L + (L_r \text{ or } R)$

$0.9D + (L_r \text{ or } R)$

$D + 0.8L + (L_r \text{ or } S)$

$0.9D + (L_r \text{ or } S)$

where D is the dead load

L is the live load

L_r is the roof live load

R is the extreme rainfall load on the roof

S is the snow (considering snow and combinations of snow, rain, and ice) load on the roof

7.5.4.2.3 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.

7.5.5 Site Drainage and Roof Design Considerations

7.5.5.1 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.

7.5.5.2 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.

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

7.5.5.4 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.

7.5.5.5 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, it may be concluded that the site storm water management system is adequate.

7.5.5.6 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.

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

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

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

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

7.5.5.11 Roof drainage systems should be designed according to applicable regulations.

7.5.5.12 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.

7.5.5.13 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.

8.0 Criteria and Guidelines for Volcanic Eruption Design

The primary design considerations relative to volcanic hazards are from volcanic ash, which can deposit hundreds of kilometers downwind of an eruption. Designing facilities to withstand the effects of more localized 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, and Los Alamos National Laboratory). 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 volcanic vent shall perform a site volcanic hazards assessment (VHA). Potential volcanic hazards to be assessed include:

- Ashfall (tephra);
- Lava flows;
- Ballistic projections;
- Pyroclastic flows;
- Mudflows (lahars);
- Low-level proximal seismic activity;
- Ground deformation;
- Tsunami (this is addressed separately in Section 5);
- Atmospheric effects, such as lightning and downburst winds; and
- 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. Higher VEI eruptions are less common than low VEI eruptions.

8.3.2 World-wide eruption data indicate that ashfall impacts from on nuclear facility SSCs 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 other precipitation loads.

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 USGS publications, DOE contractor technical reports, and published geology literature. This information shall include parameters such as eruption ages, estimated volumes, eruption physical 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 the 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, 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 Volcanic eruption 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 concentration 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, as well as an assumption of average ash particle size and thus settling velocity, an estimate of cloud density in grams of ash per cubic meter can be obtained.

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

8.3.15 If local topography would prevent any of these hazards from impacting the facility, this shall be documented and no further evaluation is required. If topography is not an adequate barrier, 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 design SSCs in a nuclear facility for volcanic eruption hazards, these shall be categorized using the categorization process and the dose criteria given in Section 2 and Table 2-1. Accordingly, for nuclear facilities, unmitigated consequence of an SSC failure resulting from volcanic eruptions shall be evaluated and compared to Table 2-1 dose criteria to determine appropriate SSC VDC (i.e., VDC-1 through VDC-5). Target performance goals (TPGs) for the five design categories can be selected to be the same as those for seismic hazards given in Table 1-3 of ASCE/SEI 43-05.

8.4.2 Ash loads, if applicable for VDC-1 through VDC-5 nuclear SSCs, shall be based on site-specific probabilistic volcanic eruption hazard studies using return periods that are based on the TPGs (see Section 8.4.1, above) and estimated risk reduction factors (RRFs), (see Section 8.4.3, below). The design and evaluations of VDC-3 through VDC-5 SSCs shall be performed using ACI-349-06 and ANSI N690-06 provisions with the following load combinations, in additions to the basic combinations:

$D + 0.8L + (L_r \text{ or } V)$

$0.9D + (L_r \text{ or } V)$

Where, D is the dead load

L is the live load

L_r is the roof live load

V is the ash load from volcanic eruptions

For VDC-1 and VDC-2, the load combinations in ASCE 7-10 shall be used substituting the ash load, V, for the snow load, S, in the load combinations.

8.4.3 For structural design considerations, RRFs may be used to increase the annual probability of hazard exceedance above the performance goals. An RRF is the ratio of the design basis annual probability of hazard exceedance to the performance goal annual probability of exceedance, and it represents conservatism employed in the design or evaluation process. An example of employing RRFs for ashfall at the Hanford Site appears in a 1996 report by Conrads, *Volcanic Ashfall Loads for the Hanford Site*.

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. Density of uncompacted ash generally decreases with distance from a volcano, and a typical range is 0.5-1.3 g/cm^3. 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/cm^3 as shown in a 2011 USGS document, *Volcanic Ash: Effects & Mitigation Strategies*. 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 concentration estimates, which, as stated above, may be very imprecise, and a likely eruption duration of 12 hours minimum shall be considered in ventilation system design. Key considerations will be filter loading time, cooling coil fouling, 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 a volcanic 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. The following documents may be beneficial.

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, Recommendations for Assessing Volcanic Hazards at Sites of Nuclear Installations, in Volcanic and Tectonic Hazard Assessment for Nuclear Facilities,* provides 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.

9.0 Evaluation and Modification of SSCs in Existing Facilities

This section provides criteria and guidance for existing hazard categories 1, 2 and 3 nuclear facilities with SSCs in NDC-3 or higher for:

- NPH design and evaluation of SSCs in existing facilities for major modifications (the term "major modification" is defined in DOE-STD-1189-2008);
- Periodic review and update of NPH assessments;
- Facility condition assessments; and
- Potential evaluation and upgrading/modification of SSCs due to changes in the NPH assessments.

Criteria and guidance for evaluation of existing nuclear, radiological, and chemical hazard facilities with SSCs in NPH Design Categories below NPH Design Category 3 is given in Section 2.1.4

9.1. NPH Design and Evaluation of Existing Facilities for Major Modifications

For major modifications of existing facilities, the design of SSCs shall be based on the methods and criteria given in this standard for new facilities with the following caveat. On a case-by-case basis, analyses may be performed to evaluate the need to upgrade existing SSCs (including interfacing SSCs) in accordance with these criteria. Sections 9.3 and 9.4 provide guidance on the conduct of such analyses. The analyses shall be submitted to the DOE for approval, in the form of a report or a section in the project's Safety Design Strategy (see DOE-STD-1189), with recommendations and justification for the recommendations.

9.2. Periodic Review and Update of NPH Assessments

9.2.1 At a frequency not to exceed ten years, the following aspects of NPH assessments shall be reviewed for changes that would warrant updating the assessments:

- NPH data and data collection methods;
- NPH modeling techniques, either generic or specific to the region of interest; and
- NPH assessment methods.

9.2.2 Consistent with DOE 420.1C, a preliminary estimate of whether changes to data, models, or methods are "significant" and warrant updating the assessments should be performed and consider the following criteria:

- Are the changes to data, models, or methods likely to cause a change in the estimates of the major inputs to hazard calculations?
- Given potential changes to the hazard inputs, by what magnitude might the calculated hazard results change, and how might the results impact current site design standards?

9.2.3 The preliminary estimate of how hazard results might change from new inputs will likely be imprecise. An expected significant increase in the hazard results would clearly favor completion of a new assessment. However, even if hazard results are not expected to change significantly, large changes to the input parameters may warrant a new assessment to ensure the NPH assessment continues to have a viable technical basis.

9.2.4 In the case of seismic hazard assessments, a determination of whether an existing assessment remains adequate for future use should consider the criteria in Section 4.1 of ANSI/ANS-2.29-2008 for the suitability of existing studies. Additional guidance on the bases for updating existing seismic assessments can be obtained from NUREG-2117, *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies*.

9.2.5 A decision on updating an NPH assessment should consider the intended application of the assessment results. Such considerations include:

- The number of facilities affected by the NPH assessment, and the hazards posed by the facilities;
- The life-cycle stages of the facilities affected by the NPH assessment;
- Whether the assessment results will be used as design input for any future facilities;
- NUREG-2117, Chapter 6; and
- NUREG-CR 6372, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and use of Experts*, Appendices Vol. 2, Appendix G.

9.2.6 If the review and evaluation of the changes warrants an update, the updated assessment shall be performed following the criteria in this Standard for new facilities.

9.2.7 If the review and evaluation of the changes does not warrant an update, the review and evaluation results shall be justified and documented.

9.3. Facility Condition Assessments

9.3.1 Facility condition assessments performed as a result of an updated NPH assessment are required only for hazard category 1, 2, and 3 nuclear facilities. The following subsections describe the decision process to proceed with a quantitative NPH evaluation of affected SSCs, development of NPH mitigation plans, and collection of data to support evaluations.

9.3.2 If an updated NPH assessment results in an NPH level that exceeds the level used for the facility and/or SSCs in the current Documented Safety Analysis (DSA), an assessment shall be performed to determine if the NPH design of facility and/or SSCs may not meet the design criteria given in this Standard for new facilities. This assessment should be performed by subject matter experts based on a review of the existing NPH design and evaluation basis documents and the results of the updated NPH assessment, and should be peer reviewed.

9.3.3 If the peer-reviewed assessment concludes that the increase in the NPH level will not result in the failure of SSC safety function, the assessment and the peer review process and results shall be documented and submitted to DOE for review and for determining additional actions or further evaluation, if any.

9.3.4 If the peer-reviewed assessment concludes that the increase in the NPH level may result in the failure of the safety function of any SSC, a plan shall be established for a quantitative NPH evaluation of the affected SSCs using the criteria and methods given in this Standard for new facilities. The plan shall incorporate a schedule for evaluation, taking into account programmatic mission considerations, and the safety significance of the potential failure of the SSCs due to natural phenomena. The plan, along with the assessment and peer review process and results, shall be documented and submitted to DOE for review and for determining additional actions or further evaluation. Note: If the assessment identifies an Unreviewed Safety Question (USQ) or Potential Inadequate Safety Analysis (PISA), refer to DOE Guide 424.1-1B, *Implementation Guide for Use in Addressing Unreviewed Safety Question Requirements*, for additional information.

9.3.5 An NPH mitigation plan shall be developed for the SSCs that are found to have NPH design inadequacy, based on the above quantitative evaluation. This plan, to be submitted to DOE for review, shall address how the inadequacies will be rectified (physical retrofitting versus demonstration of adequacy using more refined analysis methods), and should consider cost-versus-risk reduction of potential improvements; possible time or funding constraints, and programmatic or facility mission. Also, it should incorporate a prioritized schedule for upgrading the SSCs. If a structural upgrade is required for any existing facility that can be performed quickly and inexpensively, it should be implemented.

9.3.6 Priorities should be established on the basis of the NDC (e.g., SDC, WDC, FDC, PDC, VDC), cost of strengthening, and margin between as-is SSC capacity and the capacity required by the criteria in this Standard. For SSCs which are within 10 percent of 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. It is permissible to perform such evaluations using natural phenomena hazard exceedance probability of twice the value (i.e., half the return period) specified for new design, provided that the resulting reduction in the hazard level is less than, or equal to, 20 percent. This amount of relief is within the tolerance of meeting the performance goals and is only a minor adjustment of the corresponding NPH design and evaluation criteria. In addition, it is consistent with the intent of the Federal Executive Order 12941 developed by the ICSSC. When upgrading becomes necessary, the design should be based on the design criteria for new SSCs defined in this Standard.

9.3.7 For facilities with a remaining service life of five years or less, it may not be necessary to upgrade the facility SSCs 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. The guidelines given in ICSSC RP-5 may be used for defining the "exceptionally high risk" facilities. For nuclear facilities, the designation of "exceptionally high risk" facility should additionally be based on:

- Hazard category of the facility;
- The percent by which the revised design basis ground acceleration exceeds that used in the original design;
- The total number of safety significant and safety class SSCs that do not meet the design requirements;
- The dose that a co-located worker and a member of the public may likely receive resulting from the NPH-related failure;
- The number of co-located workers and members of the public that are likely to be adversely affected; and
- Strategic and economic importance of the facility.

9.3.8 The following data and information should be collected to support the evaluation of the existing SSCs:

- The safety basis documentation to identify and list individual safety SSCs in the safety basis of the facility;
- Identification of the safety function, functional requirements and NPH performance criteria for each of the SSCs from the safety basis documentation;
- Construction or fabrication of as-built drawings and specifications of the SSCs;
- Data and information from site visits and walk-downs performed to verify that the SSCs are built according to written plans and specifications;
- Modifications not shown on the drawings or physical deteriorations;
- Documents that establish an appropriate determination of material properties to be used in the analyses; and
- Data related to ductile design details that are necessary to evaluate the appropriate inelastic energy absorption factor, F_μ, that can be used for seismic re-evaluation.

Using the above data and information, an evaluation of the SSCs should be performed using the criteria given in this Standard. For the SSCs that do not meet the criteria, a revised evaluation should be performed using median values of material properties if median values were not used in the original design (the use of median values of material properties should 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). Applicable industry practice should be followed in developing sampling criteria to determine median values.

9.4. Guidelines for NPH Evaluation of SSCs in Existing Facilities

Note: The sections below provide additional guidelines for different NPHs (e.g., seismic, wind, flood and precipitation).

9.4.1 Seismic Evaluation. To comply with Public Law 102-614 and Executive Order 12941, the guidelines provided in ICSSC RP-8, shall be used to: determine when a seismic evaluation and retrofitting of existing nuclear facility will be necessary; and establish the evaluation and mitigation requirements.

In addition, general guidelines for the seismic evaluation of existing facilities presented in the following documents should also be considered:

- *Techniques for the Seismic Rehabilitation of Existing Buildings*, FEMA 547, 2006;
- *Rehabilitation of Existing Buildings*, ASCE/SEI 41-06, Structural Engineering Institute of the American Society of Civil Engineers, 2006;
- *Standard for the Seismic Evaluation of Buildings*, ASCE/SEI 31-03, Structural Engineering Institute Of the American Society of Civil Engineers, 2003;
- *Seismic Evaluation Procedure for Equipment in U.S. Department of Energy Facilities*, DOE-EH-0545, 1997; and
- *Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment*, Revision 3A, Seismic Qualification Utility Group, 1997.

These documents, and the peer-reviewed consensus documents referenced therein, should be used to develop a plan and criteria document for evaluating seismic adequacy of existing facilities, as well as for specific guidelines on upgrading and retrofitting until a revision or addendum to this section of this Standard is published by DOE that provides specific guidelines as to seismic upgrading or retrofitting of existing DOE facility SSCs. The plan should consider cost-versus-risk-reduction and remaining facility life to prioritize detailed and refined seismic evaluation, and upgrading of candidate facilities. High priority should be given to those SSCs identified as weak links by the preliminary investigation and to SSCs that are most important to personnel safety and operations with hazardous materials. Input from safety personnel and/or accident analyses should be used as an aid in determining safety priorities.

Once the as-is condition of a facility has been verified and deficiencies or weak links have been identified, detailed seismic evaluation and/or upgrading of the facility should be considered. Obvious deficiencies that can be readily improved should be remedied as soon as possible. A realistic schedule to address all safety-related deficiencies shall be developed.

Seismic evaluation for existing facilities would be similar to evaluations performed for new designs except that a single as-is configuration is evaluated instead of several configurations in an iterative manner (as is often required in the design process). The evaluation of existing facilities for seismic hazards can result in a number of options based on the evaluation results. If the existing facility can be shown to meet the design and evaluation criteria presented in Section 3 and good seismic design practice had been employed, the facility would be judged to be adequate for potential seismic hazards to which it might be subjected. If the facility does not meet the seismic evaluation criteria of Section 3, an analysis should be conducted to determine appropriate action. Several alternatives may be considered:

- If an existing SSC is close to meeting the criteria, a slight increase in the annual risk to natural phenomena hazards can be allowed within the tolerance of meeting the target performance goals (See Section 9.3). Note that reduced criteria for seismic evaluation of existing SSCs is supported in NISTIR 890-4062, *Guidelines for Identification and Mitigation of Seismically Hazardous Existing Federal Buildings* and ICSSC RP-8 documents. As a result, some relief in the criteria may be allowed by performing the evaluation using higher hazard exceedance probability as permitted in Section 9.3, above.

- The SSC may be strengthened such that its seismic resistance capacity is sufficiently increased to meet these seismic criteria. When upgrading is required, it should be designed for the current design criteria.

- The usage of the facility may be changed such that it falls within a less hazardous performance category and, consequently, less stringent seismic requirements.

- It may be possible to conduct the aspects of the seismic evaluation in a more rigorous manner that removes conservatism such that the SSC may be shown to be adequate. Alternatively, a probabilistic assessment might be undertaken in order to demonstrate that the performance goals can be met.

9.4.2 Wind Hazard Evaluation. The following guidelines may be used for evaluating WDC-1 through WDC-5 SSCs in an existing facility:

9.4.2.1 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 which results in wind and water damage to the building contents. Also, in-situ strengths of existing structures need to be adequately estimated when required.

9.4.2.2 Experience from wind storm damage investigations provides the best guidelines for anticipating the potential performance of existing SSCs under wind loads. Mehta *et al*, *Procedures for Predicting Wind Damage to Buildings,* provides a methodology for estimating the performance of existing SSCs based on identification of weak links in the building structure. The approach is directed primarily to structures, but can be adapted to systems and components as well.

9.4.2.3 The methodology described in Mehta *et al*, *Procedures for Predicting Wind Damage to Buildings,* involves two levels of evaluation:

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

- The Level II process includes the following three steps:
    - Data collection;
    - Analysis of element failures; and,
    - Postulation of failure sequence.

9.4.3 Flood Hazard Evaluation. The following guidelines may be used for evaluating FDC-1 through FDC-5 SSCs in an existing facility:

9.4.3.1 SSCs in existing facilities may be situated below the DBFL as defined in this Standard. In this case, an evaluation shall be performed to determine the level of external flooding, if any, that can be sustained, without negating the SSC functional safety requirements.

9.4.3.2 This level is referred to as the Critical Flood Elevation (CFE). If the CFE is higher than the DBFL, no further evaluation will be necessary.

9.4.3.3 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.

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

- Below grade due to the structural flooding vulnerability of exterior walls or instability due to uplift pressures on supporting or enclosing the safety function of the structure;
- At the elevation of utilities that support SSCs; or
- At the actual base elevation of an SSC.

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 safety function failure (e.g., critical equipment or materials may be located above the first floor). If the CFE for an SSC exceeds the DBFL, the design criteria is satisfied. If the CFE does not exceed the DBFL, options shall be considered to harden the SSC or relocate it.

9.4.4 Precipitation Hazard Evaluation. The following guidelines are provided for use in evaluating PDC-1 through PDC-5 SSCs in an existing facility:

9.4.4.1 The precipitation evaluations of the SSCs may be performed using the same criteria as for new facilities; and

9.4.4.2 For SSCs that are impacted by the precipitation evaluations, the following mitigation measures can be considered:

- modifying roofs to minimize ponding on the roofs, such as removing roof parapets, increasing the size and number of scupper openings in the roof parapets;
- providing protective shielding structures for critical SSCs to prevent water intrusion from potential roof leaks;
- relocating critical SSCs away from potential roof leaks;
- providing protective dikes around the facility;
- relocating critical SSCs to higher elevations in the facility to protect from precipitation runoff;
- modifying site grading or provide detention ponds to protect the facility; and
- implementing emergency operations plans to secure areas where critical SSCs are located.

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 requirements of DOE O 414.1D, *Quality Assurance*, using a graded approach and an approved quality assurance plan. In addition, for nuclear facilities, as defined in 10 C.F.R. § 830.3, *Nuclear Safety Management Rule*, ASME NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*, Part I and applicable requirements of Part II, shall be the preferred consensus standard for developing the quality assurance plan. Additional quality assurance and peer review requirements from ASCE/SEI 43-05 and ANSI/ANS 2.29 shall be implemented, as applicable, to supplement the requirements set forth above. The 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 for design categories 3, 4 and 5.

References

Executive Orders

Executive Order 12941, *Seismic Safety of Existing Federally Owned or Leased Buildings*, 1994

Code of Federal Regulations

U.S. Department of Energy, *Nuclear Safety Management Rule,* 10 C.F.R. § 830.3, 2001

DOE Directives

DOE O 414.1D, *Quality Assurance,* 2011

DOE O 420.1C, *Facility Safety*, 2012

DOE O 450.1A, *Environmental Protection Program,* 2003

DOE O 458.1, Change 2, *Radiation Protection of the Public and the Environment,* 2011

DOE M.440.1-1A, *Explosives Safety,* 2006

DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear and Non-Nuclear Facilities*, 2002

DOE G 424.1-1B, *Implementation Guide for Use in Addressing Unreviewed Safety Question Requirements,* 2010

DOE Technical Standards

DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, 2002

DOE-STD-1021-93 (Reaffirmed in 2002), *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*, 1993

DOE-STD-1022-94 (Reaffirmed in 2002), *Natural Phenomena Hazards Site Characterization Criteria,* 1994

DOE-STD-1023-95 (Reaffirmed in 2002), *Natural Phenomena Hazards Assessment Criteria*, 1995

DOE-STD-1066-2012, *Fire Protection,* 2012

DOE-STD-1189-2008, *Integration of Safety into the Design Process,* 2008

DOE-STD-1212-2012, *Explosives Safety,* 2012

DOE-STD-3009-94, Change Order 3, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facilities Documented Safety Analyses*, 2006

Other DOE Documents

DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, 2004

DOE/EH-0545, *Seismic Evaluation Procedure for Equipment in U.S. Department of Energy Facilities*, 1997

Hossain, Quazi, et al, Technical Support Document for DOE-STD-3014-2006 (Accident Analysis for Aircraft Crash into Hazardous Facilities), *Structures, Systems, and Components Evaluation Technical Support Document*, UCRL-ID-123577, 1996

McCann, M.W. and A.C. Boissonnade, *Preliminary Flood Hazard Estimates for Screening Models for Department of Energy Sites*, Lawrence Livermore National Laboratory, UCRL-21045, 1988

U.S. Nuclear Regulatory Commission Documents

NUREG-2117, *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies*, 2012

NUREG/CR-6372, *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts*, 1997

NUREG/CR-6728, *Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines*, 2001

Regulatory Guide 1.76, Rev. 1, *Design Basis Tornado and Tornado Missiles for Nuclear Power Plants*, 2007

Regulatory Guide 1.102, *Flood Protection for Nuclear Power Plants,* 1976

Regulatory Guide 1.208, *Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*, 2007

Regulatory Guide 1.221, Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants, 2011

Standard Review Plan, NUREG-0800, Section 2.4.10, Revision 3, *Flooding Protection Requirements,* 2007

Standard Review Plan, NUREG-0800, Section 2.5.5, Revision 4, *Stability of Slopes,* 2010

Standard Review Plan, NUREG-0800, Section 3.4.2, Revision 3, *Analysis Procedures*, 2007

National Institute of Standards and Technology Documents

NISTIR 890-4062, ICSSC RP-3, *Guidelines for Identification and Mitigation of Seismically Hazardous Existing Federal Buildings,* 1989

NISTIR 5734, ICSSC RP-5, *ICSSC Guidance on Implementing Executive Order 12941 on Seismic Safety of Existing Federally Owned or Leased Buildings*, 1995

NIST GCR 11-917-12, ICSSC RP-8, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings,* 2011

Other Government Documents

Federal Emergency Management Agency, FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings*, 2006

Non-Government Standards

American National Standards Institute/American Institute of Steel Construction

ANSI/AISC N690-06, *Specification for Safety-Related Steel Structures for Nuclear Facilities*, 2006

American National Standards Institute/American Nuclear Society

ANSI/ANS-2.26-2004 (R2010), *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design*, 2004

ANSI/ANS-2.27-2008, *Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessment*, 2008

ANSI/ANS-2.29-2008, *Probabilistic Seismic Hazards Analysis*, 2008

ANSI/ANS-2.3-2011, *Estimating Tornado, Hurricane, and Extreme Straight-Line Wind Characteristics at Nuclear Facility Sites*, 2011

ANSI/ANS-3.11-2010, *Determining Meteorological Information at Nuclear Facility Sites*, 2010

ANSI/ANS-8.1-1998 (R2007), *Nuclear Criticality Safety I Operations with Fissionable Materials Outside Reactors*, 1998

American Society of Civil Engineers

ANSI/ASCE 1-82, N-725, *Guideline for Design and Analysis of Nuclear Safety Related Earth Structures*, 1982

ASCE 4-98, *Seismic Analysis of Safety-Related Nuclear Structures,* 1998

Report of the ASCE Committee on Impactive and Impulsive Loads, Volume V, Civil Engineering and Nuclear Power, September, 1980

Manuals and reports on Engineering Practice, No. 58, *Structural Analysis and Design of Nuclear Plant Facilities,* 1980

American Society of Mechanical Engineers

ASME NQA-1-2008 with the NQA-1a-2009 addenda, *Quality Assurance Requirements for Nuclear Facility Applications,* 2009

National Fire Protection Association

NFPA 780-2011, *Standard for the Installation of Lightning Protection Systems*, 2011

Structural Engineering Institute of the American Society of Civil Engineers

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, 2010

ASCE/SEI 7-05, *Minimum Design Loads for Buildings and Other Structures*, 2005

ASCE/SEI 7-02, *Minimum Design Loads for Buildings and Other Structures*, 2002

ASCE/SEI 31-03, *Standard for the Seismic Evaluation of Buildings,* 2003

ASCE/SEI 41-06, *Rehabilitation of Existing Buildings,* 2006

ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities*, 2005

Other

American Concrete Institute, ACI 349-06, *Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary,* 2006

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

Electric Power Research Institute, Program on Technology Innovation, Technical Report 1012965, *Use of CAV in Determining Effects of Small Magnitude Earthquakes on Seismic Hazard Analyses*, Palo Alto, CA, 2005

Hill, B.E., Aspinall, W.P., Connor, C.B., Komorowski, J.-C., and Nakada, S., *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., 2009

Hoblitt, R.P., and Scott, W.E., *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, 2011

International Atomic Energy Agency, *Volcanic Hazards in Site Evaluation for Nuclear Installations*, Draft Specific Safety Guide DS 405, 2010

Kennedy, Robert, *A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects, Nuclear Engineering and Design*, Volume 37, North Holland Publishing Company, 1976

Mehta, K. C., McDonald, J. R., and Smith, D. A., *Procedures for Predicting Wind Damage to Buildings,* Journal of the Structural Division, ASCE, Vol.107, No. ST 11, 2089-2096, 1981

Newhall, C.G., and Hoblitt, R.P., *Constructing Event Trees for Volcanic Crises*, Bulletin of Volcanology, v. 64, pp. 3-20, 2002

Newhall, C.G., and Self, S., *The Volcanic Explosivity (VEI): An Estimate of Explosive Magnitude for Historical Volcanism*, Journal of Geophysical Research, v.87, pp. 1231-1238, 1982

Seismic Qualification Utility Group, *Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment*, Revision 3A, 1997

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

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 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]

Safety Class Structures, Systems, and Components: The structures, systems, or components, including portions of process systems, whose preventive or mitigative function is necessary to limit radioactive hazardous material exposure to the public, as determined from safety analyses: [Source 10 C.F.R. 830]

Safety Significant Structures, Systems, and Components: The structures, systems, and components which are not designated as safety class structures, systems, and components, but whose preventive or mitigative function is a major contributor to defense in depth and/or worker safety as determined from safety analyses. [Source 10 C.F.R. 830]

Safety Structures, Systems, and Components: The set of both the safety class structures, systems, and components, and the safety significant structures, systems, and components. [Source 10 C.F.R. 830]

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]

Return Period and Annual Probability of Exceedance: The likelihood of natural phenomena hazards are evaluated on a probabilistic basis for these performance goal-based NPH criteria. The frequency of occurrence of parameters describing the external hazard severity (such as earthquake ground acceleration, wind speed, or depth of inundation) is estimated by probabilistic methods. Common frequency statistics employed for rare events such as natural phenomena hazards include return period and annual probability of exceedance. Return period is the average time between consecutive events of the same or greater severity (for example, earthquakes with maximum ground acceleration of 0.2g or greater). The return period is only an average duration between events and should not be construed as the actual time between occurrences, which would be highly variable. A given event of return period, self straining force (T), is equally likely to occur any year, thus the probability of that event being exceeded in any one year is 1/T. The annual probability of exceedance, p, of an event is the reciprocal of the return period of that event (i.e., p = 1/T). As an example, consider a site at which the return period for an earthquake of 0.2g or greater is 1,000 years. In this case, the annual probability of exceedance of 0.2g is 10^{-3} or 0.1 percent.

It is of interest in the design of facilities to define the probability that an event will be exceeded during the design life of the facilities. For an event with return period, T, and annual probability of exceedance, p, the exceedance probability, EP, over design life, n, is given by:

(A-1) $EP = 1 - (1 - p)^n = 1 - (1 - 1/T)^n \; 1 \approx e^{-n/T}$

Where EP and p vary from 0 to 1, and n and T are expressed in years. As an example, the exceedance probabilities over a design life of 50 years of a given event with various annual probabilities of exceedance are as follows:

p	EP over 50 years
10^{-3}	0.05
10^{-4}	0.005
10^{-5}	0.0005

Hence, an event with a 10^{-3} annual probability of exceedance (1,000 year return period) has a 5 percent chance of being exceeded in a 50-year period, while an event with a 10^{-4} annual probability of exceedance has only a 0.5 percent chance of being exceeded during a 50-year period.

Appendix B. Abbreviations and Acronyms

ACI	American Concrete Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
APC	Atmospheric Pressure Change
ASCE	American Society of Civil Engineers
CFE	Critical Flood Elevation
CFHA	Comprehensive Flood Hazard Assessment
C.F.R.	Code of Federal Regulations
COE	U.S. Army Corps of Engineers
D	Dead Load
DBE	Design Basis Earthquake
DBFH	Design Basis Flood Hazard
DBFL	Design Basis Flood Level
DBPL	Design Basis Precipitation Level
DOE	Department of Energy
DSA	Documented Safety Analysis
EF	Enhanced Fujita scale
F	Loads due to normal flood
F_a	Hydrostatic and Hydrodynamic (including wave and impact) loads
FDC	Flood Design Category
FEMA	Federal Emergency Management Agency
FIA	Flood Insurance Administration
FSA	Flood Screening Analysis
G	Guide
I	Importance Factor
IAEA	International Atomic Energy Agency
IBC	International Building Code
ICC	International Code Council
ICSSC	Interagency Committee on Seismic Safety in Construction
L	Live Load
L_r	Roof Live Load
LS	Limit State
M	Manual

MLW	Mean Low Water
NCDC	National Climatic Data Center
NDC	NPH Design Category
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NPH	Natural Phenomena Hazard
NRC	Nuclear Regulatory Commission
NUREG	NRC technical document
NWS	National Weather Service
O	Order
PDC	Precipitation Design Category
PFHA	Probabilistic Flood Hazard Assessment
PMWP	Probable Maximum Winter Precipitation
PPHA	Probabilistic Precipitation Hazard Assessment
PSHA	Probabilistic Seismic Hazard Assessment
PWHA	Probabilistic Wind Hazard Assessment
RRF	Risk Reduction Factor
S	Snow Load
SDC	Seismic Design Category
SEI	Structural Engineering Institute
SFE	Supercritical Fluid Extraction
SG	Seismic Use Group
SME	Subject Matter Expert
SSC	Structure, System and Component
STD	Standard
T	Self Straining Force
TEDE	Total Effective Dose Equivalent
TPG	Target Performance Goal
TVA	Tennessee Valley Authority
UHS	Uniform Hazard Spectrum
USGS	United States Geological Survey

VDC	Volcanic Design Category
VEI	Volcanic Explosivity Index
VHA	Volcanic Hazards Assessment
W	Extreme straight-line wind, hurricane wind, or tornado windload
W_n	Normal wind
WDC	Wind Design Category

CONCLUDING MATERIAL

Review Activity:	Field and Operations Offices	Preparing Activity:
HSS	CBFO	HS-32
NNSA	CH	
EM	ID	**Project Number:**
NE	OH	NPHZ-0003
SC	OR	
CTA/CNS	ORP	
CTA/CDNS	RL	
	SR	

Site Offices:

Argonne Site Office
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