IAEA SAFETY STANDARDS
for protecting people and the environment

Step 8: Soliciting comments by Member States

External Events Excluding Earthquakes in the Design of Nuclear Installations

DRAFT SAFETY GUIDE No. DS 498

Revision of Safety Guide NS-G-1.5

FOREWORD

Later

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide provides recommendations on the design of nuclear installation for External Events (EEs) excluding earthquakes to meet the requirements established in: IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1]; IAEA Safety Standards Series No. SSR-3, Safety of Research Reactors [2]; and IAEA Safety Standards Series No. SSR-4, Safety of Nuclear Fuel Cycle Facilities [3], with reference to IAEA Safety Standard Series No. SSR-1, Site Evaluation for Nuclear Installations [4], which defines external hazards that need to be considered.

1.2. This publication is a revision of IAEA Safety Standard Series No. NS-G-1.5[1], which it supersedes. The revision incorporates the progress in terms of best practice, lessons identified from extreme EEs, feedback from safety review missions and the results of research on the effects of all EEs[2] excluding earthquakes that have taken place since the publication of NS-G-1.5 in 2003.

1.3. The main topical areas for which this Safety Guide provides new or updated recommendations are the following:

(1) General concept and application of safety criteria to the design of structures, systems and components (SSCs) for protection against EEs, load combinations and acceptance criteria;
(2) Safety analysis for Design Basis External Events (DBEEs) and Beyond Design Basis External Events (BDBEEs);
(3) Design basis for each external event;
(4) Categorization of SSCs,
(5) Design and qualification methods and means of protection for a broad range of nuclear installations, i.e. land based stationary nuclear power plants, research reactors, nuclear fuel fabrication facilities, enrichment facilities, reprocessing facilities and independent spent fuel storage facilities [5];
(6) Application of the management system.

1.4. This Safety Guide provides recommendations for DBEEs[3] and BDBEEs excluding earthquakes, while related Safety Guides [6–9] provide recommendations on the assessment of

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, External Events Excluding Earthquakes in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.5, IAEA, Vienna (2003).

[2] An external event is an event that originates outside the site and whose effects on the nuclear installation should be considered. Such events could be of natural or human induced origin and are identified and selected for design purposes during the site evaluation process. Events originating on the site but outside the safety related buildings should be treated the same as offsite EEs.

[3] A design basis external event is an external event or a combination of EEs selected for the design of all or any part of a nuclear power plant, characterized by or having associated with it certain parameter values.

hazards in site evaluation. In this Safety Guide, the term "Beyond Design Basis External Event" is used to indicate a level of external hazard exceeding those considered for design, derived from the hazard evaluation for the site and that has the purpose of evaluating the margins that exist in the design as well as the identification of potential cliff edge effects.

1.5. Other Safety Guides relating to SSR-2/1 (Rev. 1) [1], SSR-3 [2] and SSR-4 [3] present a discussion on EEs and in this sense are complementary to the present Safety Guide. Fire effects are in general addressed in IAEA Safety Standards Series No. NS-G-1.7, Protection against Fire and Fire Induced Internal Fire and Explosions in the Design of Nuclear Power Plants [10]. Certain missiles[4] (as secondary effects of explosions mainly internal to buildings) are addressed in IAEA Safety Standards Series No. NS-G-1.11, Protection against Internal Hazards other than Fire and Explosions in the Design of Nuclear Power Plants [11]. The effects of earthquakes, vibration and shaking of the ground are discussed in IAEA Safety Standards Series No. NS-G-1.6, Seismic Design and Qualification for Nuclear Power Plants [12].

OBJECTIVE

1.6. The objective of this Safety Guide is to provide recommendations and guidance on design for the protection of nuclear installations from the effects of EEs (excluding earthquakes).

1.7. This Safety Guide is intended to provide recommendations on engineering related matters in order to comply with the applicable safety requirements established in SSR-2/1 (Rev. 1) [1], SSR-3 [2] and SSR-4 [3].

1.8. This Safety Guide provides methods and procedures for defining an appropriate design envelope for a nuclear installation based on the site hazard evaluations carried out in the site characterization phase and on the specific layout of the plant.

1.9. These methods and procedures are intended to provide guidance for design and protection of the SSCs important to safety for the selected DBEEs to ensure the safety of the installation. It also provides guidance on selecting levels of BDBEE in order to check and verify margins and deal with cliff edge effects.

DBEEs should be independent of the plant layout. An engineering analysis may be necessary to develop the loading scheme to be applied to the specific numerical or experimental models selected for the design.

[4] A missile is a mass that has kinetic energy and has left its design location. The term missile is used to describe a moving object in general, but military missiles, whether explosive or not (e.g. bombs and rockets), are specifically excluded from consideration. In general, military projectiles have velocities higher than Mach 1, and are therefore usually beyond the range of applicability of the techniques described in this Safety Guide. However, for non-explosive military projectiles with characteristics lying within the quoted ranges of applicability, the techniques described may be used.

SCOPE

1.10. This Safety Guide is applicable to the design and evaluation of nuclear installations in relation to the following EEs:

Human induced events

- Aircraft crashes;
- Explosions (deflagrations and detonations) with or without fire, with or without secondary missiles, originating from off-site and on-site sources (but external to safety related buildings), such as hazardous or pressurized materials in storage;
- Release of hazardous gases (asphyxiant, toxic) from off-site or on-site storage or transport;
- Release of radioactive material from off-site sources or on-site;
- Release of corrosive gases and liquids from off-site or on-site storage or transport;
- Fire generated from off-site or on-site sources (mainly for its potential for generating smoke and toxic gases);
- Collision of ships or floating debris with accessible safety related structures, such as water intakes and ultimate heat sink (UHS) components;
- Collision of vehicles at the site with SSCs;
- Electromagnetic interference from off the site (e.g. from communication centres and portable phone antennas) and on the site (e.g. from the activation of high voltage electric switch gear and from unshielded cables);
- Flood as a result of rupture of external pipes
- Any combination of the above as a result of a common initiating event (such as an explosion with fire and release of hazardous gases and smoke).

Natural events

- Floods such as due to tides, tsunamis, seiches, storm surges, precipitation, waterspouts, dam forming and dam failures, snow melt, landslides into water bodies, channel changes and work in the channel;
- Extreme meteorological conditions (of temperature, snow, hail, frost, as well as conditions that produce subsurface freezing and drought);
- Cyclones (hurricanes, tornadoes and tropical typhoons) and straight winds;
- Dust and sand storms;
- Lightning;
- Volcanism;
- Biological phenomena;
- Collision of floating debris (ice, logs) with accessible safety related structures such as water intakes and UHS components.
- Geotechnical hazards (not associated with seismic loads)

1.11. This list might not be exhaustive for every site; other EEs, not included in the list but relevant for the site, should be identified and selected as additional EEs.

1.12. Hazards of human induced events may be affected by possible changes that have occurred in both the industrial and the transport environment since the siting process was performed. This may also be true for changes in natural hazards (e.g. because of climate changes), as indicated in

SSR-1 [4] SSR-2/1 (Rev. 1) [1]. Such changes should be considered in periodic safety reviews [13].

1.13. Throughout this Safety Guide the term External Events or 'EEs' always excludes earthquakes, which are addressed in Refs [12, 14].

1.14. External human induced events are defined as of accidental origin. Considerations of actions related to sabotage are outside the scope of this Safety Guide. Engineering safety aspects of the protection of nuclear power plants against sabotage are discussed in Ref. [15]. However, the methods described in this Safety Guide might also be applied to sabotage protection of a nuclear installation.

1.15. The recommendations in this Safety Guide apply to a variety of nuclear installations including reactor types other than water cooled reactors at stationary nuclear power plants. Much of the methodology is independent of the type of nuclear installation or the reactor type. The methodologies developed for nuclear power plants are also applicable to other nuclear installations through a graded approach. Section 6 provides guidance on the graded approach which should be followed for different types of nuclear installations.

1.16. This Safety Guide is mainly focused on the design phase; however, most of the recommendations are also applicable in the evaluation of new installations (described in Refs [16, 17]), in the periodic safety review phase [13] and in the re-evaluation of existing plants.

STRUCTURE

1.17. The general concept and application of safety criteria to the design for protection against EEs are presented in Section 2. The derivation of the design parameters from the site evaluation, the overall design approach and evaluation of BDBEEs are discussed in Section 3. Plant layout and approach to building design is presented in Section 4 along with the suitable load combinations and acceptance criteria under these together. Specific EEs are treated individually in Sections 5. Section 6 discusses safety design provisions for nuclear installations other than nuclear power plants using a graded approach. Section 7 addresses application of management system for design.

2. GENERAL CONCEPT AND APPLICATION OF SAFETY CRITERIA TO THE DESIGN FOR PROTECTION AGAINST EXTERNAL EVENTS

APPLICABLE DESIGN REQUIREMENTS

2.1. SSR-2/1 (Rev. 1) [1] includes Requirements 17 and 18 for the design of nuclear power plants, Requirement 20 for design extension conditions, and Requirements 53 and 65 for the design of heat transfer to an ultimate heat sink and the design of the control room, respectively. These requirements are of particular interest in the design of nuclear installations for EEs and the evaluation of nuclear installations for events greater than the design basis. SSR-2/1 (Rev. 1) [1] states that:

Requirement 17: Internal and external hazards

"All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered in designing the layout of the plant and in determining the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant.

"5.15A. Items important to safety shall be designed and located, with due consideration of other implications for safety, to withstand the effects of hazards or to be protected, in accordance with their importance to safety, against hazards and against common cause failure mechanisms generated by hazards.

"5.15B. For multiple unit plant sites, the design shall take due account of the potential for specific hazards to give rise to impacts on several or even all units on the site simultaneously.

"5.17. The design shall include due consideration of those natural and human induced EEs (i.e. events of origin external to the plant) that have been identified in the site evaluation process. Causation and likelihood shall be considered in postulating potential hazards. In the short term, the safety of the plant shall not be permitted to be dependent on the availability of off-site services such as electricity supply and firefighting services. The design shall take due account of site specific conditions to determine the maximum delay time by which off-site services need to be available.

"5.19. Features shall be provided to minimize any interactions between buildings containing items important to safety (including power cabling and control cabling) and any other plant structure as a result of external events considered in the design.

"5.21. The design of the plant shall provide for an adequate margin to protect items important to safety against levels of external hazards to be considered for design, derived from the hazard evaluation for the site, and to avoid cliff edge effects[5].

"5.21A. The design of the plant shall also provide for an adequate margin to protect items ultimately necessary to prevent an early radioactive release or a large radioactive release in the event of levels of natural hazards exceeding those considered for design, derived from the hazards evaluation for the site."

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[5] A "cliff edge effect", in a nuclear power plant, is an instance of severely abnormal plant behaviour caused by an abrupt transition from one plant status to another following a small deviation in a plant parameter, and thus a sudden large variation in plant conditions in response to a small variation in an input. The term 'plant parameter' in the definition of cliff edge effect, needs to be interpreted in a broad sense, as any plant physical variable, design aspect, equipment condition, magnitude of a hazard, that can influence equipment or plant performance.

Requirement 18: Engineering design rules

"The engineering design rules for items important to safety at a nuclear power plant shall be specified and shall comply with the relevant national or international codes and standards and with proven engineering practices, with due account taken of their relevance to nuclear power technology.

"5.23. Methods to ensure a robust design shall be applied, and proven engineering practices shall be adhered to in the design of a nuclear power plant to ensure that the fundamental safety functions are achieved for all operational states and for all accident conditions."

Requirement 20: Design extension conditions

"A set of design extension conditions shall be derived on the basis of engineering judgement, deterministic assessments and probabilistic assessments for the purpose of further improving the safety of the nuclear power plant by enhancing the plant's capabilities to withstand, without unacceptable radiological consequences, accidents that are either more severe than design basis accidents or that involve additional failures. These design extension conditions shall be used to identify the additional accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or mitigation of their consequences."

Requirement 53: Heat transfer to an ultimate heat sink

"The capability to transfer heat to an ultimate heat sink shall be ensured for all plant states.

"6.19B. The heat transfer function shall be fulfilled for levels of natural hazards more severe than those considered for design, derived from the hazard evaluation for the site."

Requirement 65: Control room

"A control room shall be provided at the nuclear power plant from which the plant can be safely operated in all operational states, either automatically or manually, and from which measures can be taken to maintain the plant in a safe state or to bring it back into a safe state after anticipated operational occurrences and accident conditions.

"6.40A. The design of the control room shall provide an adequate margin against levels of natural hazards more severe than those considered for design, derived from the hazard evaluation for the site."

2.2. The requirements for the design of nuclear installations other than Nuclear Power Plants (NPPs) against EEs and the evaluation of nuclear installations other than NPPs against events greater than the design basis are provided in SSR-3 [2] and SSR-4 [3].

MEETING SAFETY REQUIREMENTS

2.3. SSR-1 [4] requires proposed sites for a nuclear installation[6] to be evaluated for external natural and human induced events with emphasis on the frequency of exceedance and severity of the events. For this purpose, external event hazards should be assessed. The methods of hazard assessment can be deterministic or probabilistic. Potential combination of events should be considered.

2.4. The end products of hazard assessments should be hazard descriptors, expressed by information on the annual frequency of exceedance versus information on the severity levels of the hazards, descriptions of all hazard assessment methodological elements and parameters of importance (including screening methods and results), assumptions made in the hazard assessment process and characteristics of the hazard descriptors. This information should be communicated to the responsible design organization.

2.5. Two levels of external event hazards should be considered for the design and evaluation of those structures, systems, and components (SSCs) identified to be important for nuclear installation safe performance when subjected to EEs. The first level is the DBEE. The second level should be selected to be higher than the design basis and used in the evaluation of the nuclear installation in order to evaluate the uncertainty in external hazard estimations and safety margins. This is called the BDBEE[7].

2.6. The design organization should be responsible for defining the design loading conditions for the DBEE and the evaluation loading conditions for the BDBEE for SSCs. These loading conditions should be determined based on all data communicated from the hazard assessment organization.

SAFETY MARGIN

2.7. Paragraphs 5.21 and 5.21A of SSR-2/1 (Rev. 1) [1] emphasize the need for the design organization to provide a design with adequate margin[8] to (i) protect items important to safety against levels of external hazards and to avoid cliff edge effects; (ii) protect items ultimately necessary to prevent an early radioactive release, or a large radioactive release[9], in the case that natural events greater than those considered for design occur.

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[6] The terms “nuclear installation” and “installation” are used synonymously in this Safety Guide.

[7] For EEs that exceed the design basis, derived from the site evaluation, i.e. the magnitude for which the safety systems are designed to remain functional both during and after the external event, the term BDBEE is used in this publication.

[8] The terms ‘margins’ and ‘safety margins’ are used synonymously in this Safety Guide.

[9] An ‘early radioactive release’ in this context is a radioactive release for which off-site protective actions would be necessary but would be unlikely to be fully effective in due time. A ‘large radioactive release’ is a radioactive release for which off-site protective actions that are limited in terms of lengths of time and areas of application would be insufficient for the protection of people and of the environment [5].

2.8. The margin is understood to be the result of the variability and uncertainty of the different methods, data, assumptions and rules applied for the design that provides the SSCs the capability to safely perform even in situations more severe than those postulated in the design basis without the incurrence of cliff edge effects. The analysis should consider all applicable epistemic and aleatory uncertainties. Another source of margin is design of the SSCs for a wide range of internal and external extreme loads, for example, pressure and other environmental loads due to accident conditions, aircraft crash, tornado, pipe break, seismic loads, and the governing loads for some SSCs could be different.

2.9. With regard to the design of structures and components, margins result from both the methodology followed to define the loading conditions and compliance with stress limits defined by the design and manufacturing codes. For the purpose of this Safety Guide, the term ‘adequate margin’ refers to: (i) the nuclear installation’s overall adequate capacity to withstand the loading conditions of DBEEs and meet the applicable safety requirements; (ii) the adequate capacity of individual SSCs to perform their function when subjected to the loading conditions of DBEEs; and (iii) the avoidance of any cliff edge effects due to BDBEEs.

2.10. A DBEE and its corresponding loading conditions should be defined conservatively in terms of the associated margins, because the assessment of DBEE and the loads associated with the DBEE typically involve uncertainties.

2.11. Conditions that are beyond the design basis should be taken into account for the potential for cliff edge effects, considering the likelihood of EEs more severe than DBEE. Some example of how BDBEEs could be defined are as follows:

- By adopting a lower annual frequency of exceedance for the DBEE.
- By adopting a higher amplitude of the DBEE loading conditions for all SSCs important to safety or a subset of SSCs ultimately necessary to prevent an early radioactive release or a large radioactive release. One way of doing this is to add a factor of conservatism to the DBEE loading conditions for those SSCs.

2.12. In consideration of the BDBEE and following a best estimate approach, values of external event parameters causing cliff edge effects should be established. Adequate margin should be demonstrated. For this purpose, the demonstration should include the determination of the severity of the event causing a cliff edge effect and the estimates of the probability of occurrence at which the cliff edge effect can occur.

2.13. Margin assessment of a nuclear installation (and/or SSCs housed within) subjected to loading conditions of an EE should be performed to determine, either:

- The level of the loading conditions at which the applicable safety requirements for the installation would be compromised or the level of the loading conditions at which a function of an SSC important to safety within the installation is compromised. This process can be called a ‘margin assessment’. The scope of the margin assessment process should include the identification of weak links and areas of improvement for engineering design to ensure that the safety of the installation meets regulatory requirements. The scope of the margin assessment should also include identification of potential for cliff edge effects due to EEs and estimation of their probability of occurrence.

or

- The level of the loading conditions at which there is high confidence that the applicable safety requirements for the installation are met, including that there is no cliff edge effect due to loading conditions slightly greater than this high confidence level.

2.14. The margin assessment can be performed by probabilistic or deterministic approaches. The probabilistic approach should provide a quantitative end result of the best estimate values of the level of loading conditions at which the applicable safety requirements for the installation will be met. Alternatively, the deterministic approach should provide conservative values at which there is high confidence that the applicable safety requirements for the installation will be met. In terms of these different approaches:

- In the probabilistic approach, the best estimate value should be defined by the mean or median values of the loading conditions. The best estimate value should be calculated by full probabilistic models of the loading conditions, response of the installation, and the capacity of SSCs important to safety of the installation. It should also be convolved over the range of their values or as a point estimate using a simple best estimate model in which the loading condition is defined as the mean or median value and assigning all installation parameters to their best estimate values.
- In the deterministic approach, a metric should be defined for the margin assessment. One such approach may involve the ‘High Confidence of Low Probability of Failure’. This approach is commonly used in seismic margin assessments [14].

2.15. Safety margins to be taken for various external hazards depend on the attributes of these hazards. Some attributes potentially increase the severity or the consequences of EEs, or potentially mitigate the effects of EEs. The factors shown below should be considered in defining safety margins.

a) Factors that potentially make the effects of the external event on a nuclear installation (especially on an NPP) more severe:
- Potential for causing cliff edge effects;
- Uncertainties in the hazard derivation (database issues – completeness and constraints for maximum values);
- Insufficient experience in specific EEs – maturity of subject matter and nuclear installation experience;
- Potential for combination with other EEs – dependency (high winds and/or flood, earthquake ground motion, fault displacement, tsunami);
- Potential for an EE to cause an important internal-event phenomenon (e.g. earthquake causes internal fire or flood)
- Extent of common cause failure (e.g. on a multiple unit NPP site):
    - Simultaneous effects on all SSCs in one NPP unit, multiple NPP units on site, multiple NPP sites;

- Correlation of performance of systems – potential compromise of redundancy of systems, defence-in-depth;
- Simultaneous challenge to on-site and off-site emergency response measures.

b) Factors that potentially mitigate the effects of EEs on a nuclear installation:

- Potential for advanced warning:
  - Warning time in hours – extreme weather conditions or external flooding (hurricane/cyclone, river flood, tsunami from distant source) – dust in air intake (volcano eruption, sand storm);
  - Warning time in minutes or less – seismic ground motion (automatic seismic trip system); extreme wind (tornado).
- Sufficient time to shut down the reactor (orderly or scram);
- Extent of common cause failure:
  - Limited spatial effect (footprint) – extreme wind (tornado), aircraft crash.

2.16. In the evaluation of the safety of the nuclear installation in relation to BDBEEs, acceptance criteria applicable to the treatment of design extension conditions (DEC) should be applied.

2.17. In terms of margins, nuclear codes and standards implicitly or explicitly yield the margin achieved in the design process for individual SSCs. The safety margin for individual SSCs (i.e. the margin that results from the consideration of a variety of load cases) or for the complete nuclear installation should be achieved through the chain of steps from specification of the loading parameters to defining and achieving the SSC performance acceptance criteria.

STRUCTURES, SYSTEMS AND COMPONENTS TO BE PROTECTED AGAINST EXTERNAL EVENTS

2.18. In the design and evaluation process for each individual EE to be considered, all items that are affected by or exposed to the EE under consideration should be identified. The list of the identified items should include all SSCs as well as any barriers or protective structures built to specifically deal with the EE.

2.19. Unless national regulations require otherwise, the categorization for EEs should follow the principles of seismic categorization, which are described in NS-G-1.6 [12]. Items identified in accordance with para. 2.18 should be considered against para. 2.14 of NS-G-1.6 [12]. The items, the characteristics of which are comparable to those of items of seismic category 1, should be categorized as EE category 1. The items of EE category 1 should be designed to withstand the respective DBEE. They should also be checked against conditions exceeding the DBEE, i.e. BDBEE, in order to demonstrate an adequate margin and avoidance of cliff edge effects at the levels close to DBEE. For NPPs, if items identified in accordance with para. 2.18 include the items below, consideration should be given to provide for an adequate margin:

a) Items that are ultimately necessary to prevent an early radioactive release or a large radioactive release;

b) Items that ensure heat transfer functions to an UHS;

c) Items of the control room.

2.20. EE category 2 should be established for SSCs whose failure could jeopardize EE category 1 SSCs. Similar to seismic category 2, it should be demonstrated that EE category 2 SSCs that have a potential for interacting with EE category 1 SSCs are effectively prevented from impairing EE category 1 SSCs with which they interact. They should either be designed for the DBEE or it should be demonstrated that their failure will not impact the safety function of the EE category 1 SSC.

GUIDELINES FOR DESIGN AND EVALUATION FOR DBEEs AND BDBEEs

2.21. Design of a nuclear installation for an EE should include any credible consequential effects of that event. EEs may challenge nuclear installation safety by different means, for example.: the deterioration of the site protection features (failure of man-made earthen structures, shielding walls, dykes); the deterioration of structural capacities (leak tightness, structure integrity, support to equipment, components, distribution systems); the impairment of equipment operation; the impairment of redundancy of function due to common cause EEs; the impairment of the operator's capability; the unavailability of the heat sink; and the unavailability of off-site power sources and off site services and resources.

2.22. Having selected the EEs to be considered for a particular site [4], the designer should evaluate their effects on the installation, including all credible secondary effects, as follows:

- When evaluating the effects of EEs on the installation, it should be ensured that realistic and credible scenarios are developed. A scenario enveloping all possible effects with a single loading condition is unduly conservative.

- For beyond design basis evaluations, deterministic or probabilistic methods should be used to assess safety margins for the EEs.

2.23. Requirement 24 of SSR-2/1 (Rev. 1) [1] states:

> "The design of equipment shall take due account of the potential for common cause failures of items important to safety, to determine how the concepts of diversity, redundancy, physical separation and functional independence have to be applied to achieve the necessary reliability"[10].

For design, the single failure criterion is only capable of dealing with random failures. Therefore, the redundancy, which is the ultimate outcome of such an analysis, might be defeated by common cause failures, typically associated with EEs that are expected to have adverse effects over relatively large areas in the site.

2.24. Unless a combination of events is shown to have a sufficiently high probability, a DBEE or a BDBEE should not be considered in combination with other rare events that may occur

[10] In some States the probability of occurrence of certain human induced events, such as external explosions or aircraft crashes, is considered very low, and the passive components are usually assumed to be designed, manufactured, inspected and maintained to an extremely high quality. Therefore, the single failure non-compliance clause (see para. 5.40 of SSR-2/1 (Rev. 1) [1]) can be applied to the passive components. In some States, system outage due to repair, test or maintenance with its associated change in plant configuration is considered one possible mode of a single failure in this context. Other States include the single failure criterion for all DBEEs.

independently, such as other external human induced events, natural phenomena, equipment failures and operator errors. When assessing a combined event, the possibility of a concurrent or causal relationship should be evaluated, in accordance with the requirements established in GSR Part 4 (Rev. 1) [16] and the recommendations provided in SSG-2 [17].

2.25. A loss of off-site power should be assumed as possibly coinciding with any DBEE or a BDBEE if a direct or indirect causal relationship cannot be excluded. In particular, for EEs that are expected to affect the entire site and, therefore, to give rise to a potential for a common cause failure mode, or for EEs that may cause a turbine or reactor trip, a loss of off-site power should be combined with the DBEE and BDBEE evaluations.

2.26. When justified, in the design or evaluation for protecting SSCs against DBEEs and BDBEEs that produce direct and indirect effects, the time delay between such effects should be taken into consideration in specifying how the direct and indirect effects are to be combined.

2.27. For phenomena of DBEEs and BDBEEs that are expected to develop slowly, the possibility of warning and precautions should be considered. In such cases, written procedures should be prepared to clearly define the lines of actions to be taken once the warning is received.

2.28. Consideration should be given to the immediate, medium term, and long-term effects of DBEEs and BDBEEs on off-site and on-site infrastructure and facilities because non-nuclear on-site infrastructure and facilities may be damaged or destroyed by the EE, e.g. on-site roads, sea harbours or landings for supply delivery.

2.29. Off-site infrastructure and assets, which, under normal circumstances, may be expected to provide various types of support to the nuclear installation may be unavailable. If the extreme conditions postulated for the site could exist for a considerable period of time (long term), the feasibility of providing any backup measure from off-site resources should be evaluated. Therefore, realistic assessments should be made of the ability to receive off-site support under extreme conditions in the site region. An adequate capacity of off-site infrastructure and assets should be ensured for such circumstances, otherwise such backup measures should be excluded from the safety analysis.

2.30. In general, for mitigation actions involving the support of off-site facilities, credit to be taken should be based on the analysis of the specific DBEE, BDBEE, and particular site conditions, and should include adequate margins for uncertainties. When presuming the occurrence of external natural and human-induced events, no credit for the support of off-site facilities, resources and services (e.g., equipment, electricity supply, firefighting services) should be allowed in the short term. Site-specific conditions should also be taken into consideration of the time for the facilities, resources and services to become available.

2.31. For the UHS, the need for make-up of heat transport fluids should be examined. Where a limited quantity of heat transport fluids is stored on site, the capability for make-up should be ensured by either (a) protecting the make-up system from EEs or (b) providing an adequate quantity of such fluids to allow time to repair the damaged part of the make-up system.

2.32. Credit for operator actions during or after the DBEE and the operator training to perform the necessary actions should be considered dependent on the specific EE and its anticipated effects on the site and SSCs. Impediments to operator actions include: lack of communication on-site, lack of mobility due to site soil failures, lack of specialized technical support needed to safely perform a recovery function, and inability to perform action due to failures or malfunctions of SSCs. No credit for operator actions should be given for the correction of equipment failures, the repair of a damage or the suppression of induced events (e.g. bushfire) as a consequence of a DBEE or BDBEE, unless there is a clear demonstration that such an action can be safely and reliably accomplished within a time frame consistent with the complexity and difficulty of the necessary action. A considerable margin should be applied to account for uncertainties, time needed to diagnose the extent of failure and to develop or modify corrective procedures, and the possible unavailability of appropriate personnel or replacement parts.

2.33. Probabilistic evaluations should be carried out for the definition of suitable design combinations between EEs and internal incidents, addressing their potential correlation.

2.34. If a challenge to a level of defence in depth is envisaged, operating procedures should be put in place for normal operation, supported by adequate warning systems (where possible) and monitoring (see the following subsections) and recognizing that pre-BDBEE and post-BDBEE actions need to be included.

DESIGN SAFETY FEATURES FOR DBEEs and BDBEEs

2.35. In designing for DBEEs, the systems design of the installation should adhere to the single failure criterion for active components, which may be achieved by means of the redundancy of safety systems or trains in a system. The acceptance criteria used in relation to DBEEs should be based on those which are applicable for DBAs.

2.36. Protection of a nuclear installation against EEs should be provided using one or more of the following basic methods;

(a) The causal influences of an external event are reduced by means of a ‘passive barrier’, e.g. ‘dry site’ for flood, site protection dam for flood, external shield for aircraft crash and barriers for explosions;
(b) Safety systems effectively resist the effects of EEs due to: (i) adequate system design, including diversity, redundancy, physical separation, and functional independence (see Requirements 21 and 24 of SSR-2/1 (Rev. 1) [1]); and (ii) adequate engineering design of SSCs when subjected to the EE loading conditions;
(c) Administrative measures, such as the establishment and enforcement of no-fly zones.

2.37. Requirements for the diversity, redundancy, physical separation and functional independence are stated in SSR-2/1 (Rev. 1) [1]. In particular, special provisions against common cause failure should be made for large and extensive systems, namely the systems used to transport heat to the UHS, pump houses, cooling towers or long piping systems with large ring main systems. A combination of the following protection strategies should be implemented:

- An adequate redundancy of safety related items. The level of redundancy should be an outcome of the application of the single failure approach to the design. Exceptions to the single failure approach may be accepted by the regulatory authority on a case by case basis.
- Adequate spatial separation between redundant components. This measure should aim to prevent common cause failures from localized EEs, e.g. missile impact, and interactions in the event of failure of one system that could be a source of failure of another. A detailed analysis of the areas of influence or expected damage from the DBEE and BDBEE should be carried out for the purpose of application of the physical separation.
- Diversity in the redundant components. In the case of external event scenarios with a potential for common cause failures, the benefits of diversity should be evaluated with care. Diversity should be combined with separation when possible.

2.38. For new designs, the design should represent the best balance among system layout, safety aspects (system and nuclear installation), operational aspects, and other important factors taking into account relevant external events for the installation.

2.39. For design modifications of an existing nuclear installation to specifically address changes in the perception of the site specific hazard, design options, such as relocating redundant systems or elements of systems, might be limited. In such cases, consideration should be given to providing additional protection in the form of barriers or retrofitting portions of systems to achieve the functional capacity needed. Options that should be considered include installing additional permanent equipment and have available (on-site and/or off-site) non-permanent (temporary) equipment, which may be mobilized if needed. The additional systems of permanent and temporary equipment should be categorized to assure their functionality when needed.

2.40. The following aspects should also be considered in a design to meet safety requirements:

- Following the occurrence of a DBEE, the design should ensure accessibility to the main control room, to the supplementary control room, and to the locations (compartments, rooms and facilities) necessary for meeting the operational requirements;
- The design should ensure that, as a consequence of DBEE, items associated with the third and fourth levels of defence in depth will not be impaired;
- The systems not protected against DBEEs should be assumed to be ‘operable’ or ‘non-operable’, depending on which status provides the more conservative scenario in the design of protection measures against the DBEE.
- On-site mobility of personnel and equipment after the occurrence of DBEE should be verified if needed.

2.41. The following aspects should also be considered in a design to meet safety requirements:

- In considering the occurrence of a BDBEE, the design should ensure accessibility to the main control room or the supplementary control room, and to the locations (compartments, rooms and facilities) necessary for meeting the requirements for response to the BDBEE.

- The systems not protected against BDBEEs should be assumed to be ‘operable’ or ‘non-operable’, depending on which status provides the more conservative scenario in the evaluation of protection measures against the BDBEE.
- On-site mobility of personnel and equipment after the occurrence of BDBEE should be verified if needed.

2.42. Provisions in the design to protect the installation against DBEEs and BDBEEs should not impair its response to other design basis events or operational procedures. In designing for additional protection, it should be borne in mind that barriers can introduce difficulties for inspection and maintenance, while a greater spread in installation layout may require more staff to handle the increased task of surveillance, as well as longer routing of piping, cable trays and ventilation ducts. A balanced design of protective measures should be made.

2.43. In the nuclear installation design for protection against EEs, adequate robustness should be used to provide the installation with additional capacity for BDBEEs for conditions in the selected EE scenarios. In general, this capacity should be provided by a combination of the following: high quality design, low sensitivity to variation in design parameters, and high and demonstrable conservatism in material selection, construction standards, and QA. An evaluation of the design conservatism should be carried out either with probabilistic tools or by deterministic bounding analysis.

ADMINISTRATIVE MEASURES

2.44. Administrative measures for DBEEs and BDBEEs are procedures and protocols that partially address the safety of the nuclear installation. Administrative measures, in conjunction with other measures, should be developed as part of the protection scheme for each EE as appropriate. Pre-event occurrence administrative measures should be based on the considerations presented in para. 2.19. When applicable, these should include measures such as the warning time and preparation time for tsunamis, hurricanes, tornadoes, and the release of hazardous gases and liquids. Furthermore, procedures and protocols should be put in place to avert hazardous situations, e.g. a no-fly zone within a given radius around the nuclear installation site, restriction of storage of on-site materials that could become wind-borne or water-borne missiles on-site or in close proximity to the site, and restriction of storage of combustible materials on site.

2.45. The effectiveness of administrative measures is strongly dependent on their enforcement level, particularly when different administrations are involved (i.e. administrations outside of the operating organization of the nuclear installation). Administrative measures should be used in conjunction with other measures, i.e., to the extent possible, they should act as an additional layer of protection. Their reliability (effectiveness) should be evaluated periodically and with care.

3. DESIGN BASIS FOR EXTERNAL EVENTS

DERIVATION OF THE DESIGN BASIS FROM THE SITE HAZARD ANALYSIS

3.1. Hazard assessment end products are specified in para. 2.4. Adequate communications with the hazard calculation teams should be maintained in order to ensure that the extent of the information and data is adequate to permit the design organization to develop the loading conditions for the EE. In addition, the information and data should be transparent and understandable to the design organization so that the development of the loading conditions is similarly transparent and understandable to stakeholders involved.

3.2. The design organization should provide information to the hazard analysis team regarding the requirements for the derivation of DBEE and BDBEE including the appropriate level of annual probability of exceedance to be considered. A feedback process between the hazard development organizations and the design organizations should be implemented.

3.3. Screening is a part of the hazard analysis. For human-induced EEs, screening by physical distance as well as severity or probability of occurrence should be used[11]. When a Screening Probability Level (SPL) approach is used for screening purposes, the hazard analysis team should be informed in advance regarding appropriate level of annual probability of exceedance to be considered.

3.4. In addition, Screening Distance Value (SDV) and SPL should be considered for screening of natural EEs.

3.5. A feedback process for screened out hazards should be implemented, in the same manner as the implementation of the feedback process between the hazard development organizations and the design organizations for the hazard parameters and loading conditions.

3.6. The general approach in the design is to establish the design loading conditions by a combination of deterministic and probabilistic methods and to proceed with the design in a deterministic manner. A detailed discussion of the appropriate approaches is contained in paras 2.19–2.27 of SSG-18 [7].

3.7. In some cases, even though the combined deterministic and probabilistic approach might identify a specific loading condition as a potential DBEE, it may still be excluded from specific analysis if it is shown that the corresponding loading conditions are completely bounded by the loading conditions of other design basis events that have already been considered. However, the

[11] In some States, a value for the probability of 10^{-7} per reactor-year is used in the design of new facilities as one acceptable limit on the probability value for interacting events having serious radiological consequences, and this is considered a conservative value for the SPL if applied to all events of the same type (such as all aircraft crashes, all explosions). Some initial events may have very low limits on their acceptable probability and should be considered in isolation (see NS-G-3.1 [9])

screened-out hazard should still be kept in the design basis to ensure that potential engineering and administrative measures to be taken for the bounding case are valid for the bounded cases.

3.8. When the hazard is defined in a probabilistic context, the site hazard should be analyzed and presented in a set of hazard curves. During the design stage, the hazard curves or a single hazard value at a given annual frequency of exceedance would be used.

3.9. The objective of the design basis selection is to keep the radiological risk due to the EE acceptably low, i.e. as low as reasonably practicable and within prescribed regulatory limits. In addition, for NPPs, the mean annual core damage frequency (CDF) and mean annual early release of radioactivity frequency (LERF) need to be within regulatory body guidelines.

3.10. To satisfy this objective, the specification of the DBEE and BDBEE conditions should include an evaluation of, (i) their likelihood of occurrence; (ii) their effects on important to safety SSCs; (iii) the consequences of the loading conditions on the SSCs' ability to meet performance requirements (failure likelihood); and (iv) the overall installation consequences with respect to the risk metrics.

3.11. To confirm compliance with the objective of para. 3.9, an appropriate deterministic or probabilistic analysis should be performed at an appropriate level of detail. For nuclear installations, the graded approach should be applied considering the inherent risks.

3.12. For each EE of interest, the possibility of the EE loading condition(s) creating a cliff edge effect is required be assessed (see para. 5.21 of SSR-2/1 (Rev. 1) [1]). The assessment should include the identification of the cliff edge effect, e.g. overtopping of a flood protection structure, the probability of its occurrence, the consequences of the cliff edge effect on the SSCs and the installation, and methods of mitigating these effects.

OVERALL DESIGN APPROACH

3.13. All operational modes should be considered at the time of occurrence of any DBEE, such as full power, hot shutdown, cold shutdown, refueling outage, maintenance and repair.

3.14. The initial conditions of the installation for the DBEE and BDBEE processes should include the effects of causal and concomitant events such as the following, as applicable:

- A causal event occurs when an earthquake induces vibratory ground motion off-site and on-site. Off-site, damage occurs to a river dam releasing water flowing to the plant. On-site, the plant shuts down and is in hot standby, but changes in the physical state of some SSCs have occurred, including some damage to seismic category 1 items [12] identified to be protective of the NPP for flooding; the state of the plant at the time of the flooding needs to be taken into account;
- A concomitant loading condition occurs for a typhoon where wind forces, extreme rainfall, and storm surge occur essentially simultaneously.

3.15. In addition, the initial conditions of the installation for the DBEE and BDBEE processes should take into account the effects of measures, which may lead to a change of state of the installation prior to the EE occurring. One example of such measure is warning time leading to shutdown of the installation.

3.16. Systematic inspections by expert engineers organized in a formal installation walkdown should be performed for new installations during commissioning: to provide final verification of the design for EEs, including also internal interactions through internal fire, flood, mechanical impact and electromagnetic interference; to verify that there are no unanticipated situations; and to provide sample verification of specific design features. The walkdown team should consist of experts in EEs, design of nuclear structures and component design, together with systems analysts and plant operators. Formal installation walkdowns should also be performed for existing installations when they are evaluated for their robustness against EEs.

DERIVATION OF DBEE LOADING CONDITIONS: GENERAL CONSIDERATIONS

3.17. The derivation of the design basis parameters and the relevant loading scheme for the selected DBEEs should be carried out consistently with the level of detail needed for the design limit[12] assessment (methods, models, calculations, and testing are closely tied – integrated – to the acceptance criteria).

3.18. The performance criteria should target, as appropriate, the overall and local structural integrity of SSCs (e.g. leak tightness, lack of perforation[13], lack of scabbing[14]; operability of equipment, components, and distribution systems) and the level of fidelity associated with the design procedures to be applied (e.g. static, dynamic, linear, non-linear, one-, two-, or three-dimensional analyses).

3.19. Care should be taken with the derivation of equivalent static loads to represent time varying effects of loading functions; this procedure is intended to be conservative when applicable and it may lead to overly conservative design loads.

3.20. Care should be taken that many of the loads corresponding to EEs described in subsequent sections, and particularly in NS-G-3.1 [9], are impacts or blast loads of short duration, rapid rise time, and characterized by limited energy or a defined momentum transfer. The loads are often localized, causing substantial local response of the individual targets but with little effect on massive structures as a whole. Load-time functions should be derived by analytical simulation or experimentation, usually on rigid targets.

3.21. If simplified engineering approaches are used in the design process, the designer should confirm their applicability to the case of interest and their conservatism needed in the design.

[12] The design limit is an interpretation of acceptance criteria in terms of design parameters (e.g. elasticity, maximum crack opening, no buckling and maximum ductility).

[13] Perforation is the state when an impacting missile has passed completely through the target.

[14] Scabbing is the ejection of irregular pieces of that face of the target opposite the impact face as a result of a missile impact.

3.22. Refined studies supported by numerical analyses and/or physical testing should be carried out for specific layout configurations, such as grouping effects among cooling towers, dynamic amplification of tall and slender stacks or, in the case of aircraft crash, the dynamic interaction effects on large and flexible slabs.

3.23. A sensitivity analysis should be conducted on input data and among different acceptable approaches.

DERIVATION OF DBEE LOADING CONDITIONS: EE SPECIFIC

3.24. Subsequent sections of this Safety Guide address specific EEs. For each external event, the DBEE and BDBEE is presented starting with screening by SDV and SPL, the categorization of SSCs, the definition of the loading conditions (parameters) associated with the DBEE and BDBEE, the design and evaluation of the SSCs when subjected to the loading conditions, and the likelihood and consequences of failure of SSCs. For each EE of interest, the possibility of the EE loading condition(s) creating a “cliff edge” effect should be assessed.

EVALUATION OF BEYOND DESIGN BASIS EXTERNAL EVENTS: CLIFF EDGE EFFECTS

3.25. Design basis should avoid cliff edge effects within the uncertainty of the DBEE values. The following information should be obtained regarding cliff edge effects: the identification of the EE for which a cliff edge effect could occur; the severity of the event at which the cliff edge effect occurs; the loading condition corresponding to triggering the cliff edge effect; and the probability of occurrence of this hazard level.

3.26. DBEE should be based on the hazard evaluation for the site. In order to assess the margins and evaluate cliff edge effects, alternatives to define the BDBEE and the associated loading conditions are:

- Define the BDBEE conditions by a factor times the DBEE loading conditions similar in concept to the requirements for Beyond Design Basis Earthquake loading conditions for new nuclear installation designs,
- Define the BDBEE conditions based on the probabilistic hazard assessment.

The key element of BDBEE is the definition of the conditions to be imposed during the design or evaluation process. In principle, BDBEE should challenge the nuclear installation, especially loading conditions that could lead to cliff edge effects.

3.27. The definition of BDBEE conditions is innately coupled to the performance and acceptance criteria for SSCs and/or the nuclear installation. Similar to those for DEC, methodologies to evaluate BDBEEs may be best estimate, i.e. relaxed from design methods and acceptance criteria.

3.28. Two different methodologies should be considered to develop information about how BDBEEs affect the risk profile of a NPP:

- A probabilistic safety analysis (PSA) of external events other than earthquake (EE-PSA) method that quantifies Core Damage Frequency (CDF), Large Early Release Frequency (LERF), Large Release Frequency (LRF)[15],
- A 'margins' method that provides an EE magnitude at or below which the analyst has very high confidence that the CDF risk arising from the EE is acceptably low.

3.29. It is expected that for many needs, the 'margins' method is likely to be sufficient to provide robust support to a decision-maker. In any case, the possibility of a cliff edge effect should be assessed for each EE of interest.

4. PLANT LAYOUT AND APPROACH TO BUILD DESIGN

INSTALLATION LAYOUT

Physical Separation

4.1 Many of the EEs described in subsequent sections can have just localized effects, namely, they can have an area of influence that does not extend to the whole plant site. In such cases, if the physical separation of the redundant independent safety systems required by Requirement 21 of SSR-2/1 (Rev. 1) [1] is sufficient, separation can effectively be used to achieve safety. When physical separation is credited, the designer should demonstrate that the plant layout is such that, for the considered external event, there will always be, out of the area of influence, items redundant to those affected.

4.2 If the area affected by an external event is limited but it is not confined to a specific location, e.g. no directional effects, the designer should comply with the recommendation stated in the previous paragraph on the assumption that the event may take place anywhere on the site.

4.3 The identification of plant areas affected by an external event should be made holistically. The possible effects on any particular function caused by the impairment of a system might not be obvious[16]. Safety systems and their support systems should be evaluated as a whole.

4.4 When there is reliance on non-permanent equipment for the achievement of a safety function, normally in BDBEE scenarios, the practicability of movement from storage locations

[15] In addition to seismic, external event PSAs have been performed for extreme flood and wind hazards.

[16] For example, the repair time for a power line damaged by an event may determine the minimum amount of stored fuel needed for the diesel generators, if the supply of diesel oil from sources nearby cannot be guaranteed. Failure of a ventilation system due to an aircraft crash may lead to a temperature rise inside a building, which in turn may cause the malfunctioning of electronic and pneumatic equipment far away from the crash area.

(off-site and on-site) to connection points on-site should be demonstrated taking into account the EEs.

Protective structures

4.5 For most of the EEs described in subsequent sections, building structures as normally designed in nuclear installations provide a good level of protection for items important to safety. Structures of buildings important to safety are normally constructed in reinforced or pre-stressed concrete, with relatively thick external walls and with few openings which, in turn, are closed by robust metal doors. Hence, from the perspective of designing against the EEs, it is good layout practice to locate items important to safety inside buildings and not leave these exposed to the outside environment. This practice should be followed to the extent possible.

4.6 There are instances in which locating an item important to safety inside a building structure is not practical or even possible. This is the case, for example, of large tanks, induced draft cooling towers or containers storing flammable or explosive substances. In such cases, whenever sufficient physical separation between redundant items cannot be demonstrated, a protective structure designed against the applicable EEs should be included in the layout.

4.7 For some EEs described in subsequent sections, the loads are such that they will govern the design of a structure intended to withstand the event. This is usually the case, for example, of large aircraft impacts. In those cases, when the principle of physical separation cannot be used, the structure should be designed to sustain the event, under the applicable acceptance criteria.

4.8 The principle of physical separation cannot be used for the containment building structure, since there is no redundant building. The following layout approaches should be considered by the designer:

- Primary containment located within either a secondary containment or an external structure capable of withstanding postulated EEs;
- Structural decoupling of inner structures from external containment, to reduce the external event loads on these structures and safety related equipment installed on them;
- Low vertical profile of containment building to reduce possibility of aircraft impact;
- Redundant, physically separated safety trains with single containment capable of withstanding postulated EEs.

4.9 Consideration should be given to the fact that, as a result of the installation layout, some structures can be effectively protecting other structures and equipment against some EEs, even though they have not been purposefully designed with this goal. For example, a building may be protecting other structures from the effects of an accidental explosion in a transportation route if the building is located in between those structures and the transportation route.

4.10 In-fill masonry walls on steel or concrete framed structures are not structurally effective against explosions. Continuous reinforced concrete walls and diaphragms should be considered for this type of loading.

Dry site concept

4.11 The ‘dry site’ concept defined in para. 7.5 of SSG-18 [7] should be considered the best layout approach for protection against floods. In following this approach, the plant grade level around buildings and other items important to safety should be located above the estimated maximum level for the flood.

4.12 When the ‘dry site’ concept cannot be applied as described in para. 4.11, the layout should include permanent flood barriers or protections, with carefully selected design bases which appropriately consider flood event characteristics and their uncertainties for flood levels as well as duration and associated effects.

4.13 Irrespective of the existence of permanent flood barriers, it is considered a good layout practice to place flood sensitive equipment that is important to safety inside buildings and/or at elevations above the level of the flood. This practice should be followed as far as possible.

Special Consideration

4.14 Attention should be paid to possible failures of SSCs not important to safety caused by EEs, and which might affect the ability of the installation to maintain safety functions.

4.15 Roof design should not permit the build-up of snow, rain or ice exceeding the roof design loads. The layout should include provisions that account for accidental clogging of drainage.

4.16 In sites prone to high winds, design should consider that light and/or slender structures are the most sensitive to wind loading (e.g. light roofs, metal stacks) and they should therefore be avoided, as far as practicable. It should be noted that wind sensitive structures that are not important to safety can be the source of wind borne missiles that can affect structures important to safety. When they cannot be avoided, metal towers and stacks should be designed to have low susceptibility to vortex shedding wind loads.

4.17 Some of the EEs can be considered as extreme events, which are more frequent than rare events. This is the case, for instance, of wind load when it does not include tornado or hurricane conditions[17]. In these cases, external event loads should be combined with normal operational loads and with loads from other extreme events, with combination factors dependent on the Member State practice. A combination of probable maximum storm surge with 10-year wind wave effects is an example of such cases.

4.18 Another factor that should be considered in the plant layout is ignition of gas or vapour accumulated in confined external areas, such as courtyards or alleys. Detonations under these conditions might result in high local overpressures. To reduce the likelihood of such events, the design should, as far as practicable, provide a compact layout devoid of long alleys and inner

[17] In some Member States, design wind speed is chosen with a 100-year return period (1% annual probability of exceedance), whereas rare design events are typically chosen with a return period of 10000 years.

courtyards, or provide adequate openings to prevent the development of an explosive concentration of gases.

APPROACH TO STRUCTURAL DESIGN

General

4.19 The design of a building against an external event is generally based on a deterministic analysis. In general, there are three ways of ensuring the safety relates functional requirements:

(a) To design the building or a protective structure to withstand the loads resulting from the design basis external event, maintaining the necessary functionality of the equipment housed by the building;
(b) To show that there is a redundant building, located out of the area of influence of the design event, housing components and systems which can satisfactorily carry out the safety functions assigned to the building (e.g. a redundant emergency diesel building);
(c) To limit the consequences of damage to the building, so that the applicable safety requirements are met.

The following paragraphs refer mainly to alternative (a) above.

Loading derivation

4.20 For each external event to be considered in the design, hazard parameters should be used to derive DBEE and BDBEE parameters usable in the design and evaluation process. Care should be exercised to maintain consistency between the results of the hazard analyses and the parameters to be used for design.

4.21 The derivation of the design basis parameters and the relevant loading scheme for the selected design basis EEs should be carried out consistently with the level of detail necessary for the design limit[18] assessment (e.g. leak tightness, perforation) and to the accuracy level associated with the design procedures to be applied (e.g. linear, non-linear, three-dimensional, dynamic).

4.22 The power of computational tools allows full 3-D Computational Fluid Dynamics (CFD) analysis of the fluid domain (impulse, in the case of wind or explosions) or finite element analysis - impact analysis in the case of aircraft crash or tornado missiles - to be used for the derivation of suitable load functions or to assess the capacity of the structure. Alternatively, very detailed research programmes have been carried out by the engineering community and, in some cases, simplified engineering approaches have been developed based on interpretation of test data or data from numerical analysis and are available for a reliable design process. A very careful assessment of the basic assumptions and applicability limits of each technique should be carried out by the

[18] The design limit is an interpretation of acceptance criteria in terms of design parameters (e.g. elasticity, maximum crack opening, no buckling and maximum ductility).

designer, to check their applicability to the case of interest and their compatibility with the general accuracy level necessary in the design.

4.23 It should be considered that specific layout configurations may require refined studies supported by numerical analyses and/or physical testing. Typical examples are the grouping effects among cooling towers under wind load, dynamic amplification of tall and slender stacks or, in the case of aircraft crash, the dynamic interaction effects on large and flexible slabs.

Load combinations and acceptance criteria

4.24 EEs may be of a very infrequent nature. In these cases, statistically independent loadings from any single event are combined with normal operational loads using unity load factors for all loadings. Multiple external event loadings need not be combined. However, all effects from a single design basis external event should be properly combined, with due attention paid to the physical meaning of the combinations. Furthermore, when a causal relationship exists between events, the effects should be properly combined, as necessary. In the case of meteorological events and floods, causal relationships are discussed in SSG-18 [7].

4.25 Acceptance criteria (e.g. functionality, leaktightness, stability) should be assessed in accordance with the category of the items (EE category 1 or EE category 2). Such criteria should be interpreted in design terms, leading to appropriate design limits (e.g. allowed leak rate, maximum crack opening, elasticity and maximum displacement).

4.26 For design basis external event loads, the design should provide for essentially elastic structural behaviour. Limited inelastic behaviour may be permitted, provided the overall structural response basically remains within the linear domain and the structure performs its safety function.

4.27 Where local inelastic deformation is intended to absorb the energy input of the load, inelastic behaviour should be considered acceptable for individual ductile structural elements (e.g. beams, slabs), provided the stability of the structure as a whole or the ability of the structural element to perform its safety function is not jeopardized.

4.28 Global structural inelastic behaviour may be considered acceptable for protective substructures (e.g. restraints and missile barriers) whose sole function is to provide protection against external event loads.

Procedures for structural design

4.29 Design procedures should be selected commensurate with the characteristics of the structure, loading functions, and acceptance criteria to meet the design limits.

4.30 In the case of numerical models used in sequence (e.g. global-local), attention should be paid to consistency between different models in order to assure that the final results are representative of the structural response and behaviour.

4.31 The level of detail of the numerical models should represent structural behaviour and it should be consistent with the specified design limits. Refined modelling and analysis (e.g. structural joints, steel rebars in reinforced concrete, structural interfaces and liners) should be reviewed and verified using other approaches.

4.32 The finite element mesh should be validated for any specific load case to be analyzed. The discretization should be appropriate for the frequency content of the loading. Short duration loads (typical in explosions) may require dedicated models, different from the traditional dynamic models used for seismic analysis.

Material properties

4.33 Material properties should be consistent and in agreement with material specification, construction and quality assurance procedures associated with the safety category of the particular item. For design basis purposes, minimum certified values of strength should be used.

4.34 In the design for impulsive loadings (e.g. explosion or impact), credit may be taken for the increase in strength due to strain rate effects. Appropriate stain rate dependent material model should be used for impact analysis.

Equipment qualification

4.35 Equipment necessary for performing safety functions during and after the occurrence of a DBEE, should be functionally qualified for the induced conditions, including vibration.

4.36 Qualification for impact or impulse loading may be quite different from qualification for earthquake induced vibrations, and therefore specific procedures should be selected, appropriate to the performance needed (stability, integrity and functionality). The qualification conditions should be compared with the demand, usually represented by vibration, impact or impulse forcing functions at the anchoring to the structural support. Adequate safety margins should be provided, in accordance with the safety category of the item.

4.37 When applicable, qualification should consider functionality under conditions of dust, smoke, humidity, extreme temperatures, corrosive atmospheres, or radioactive environments, combined with mechanical stress.

4.38 For some EEs, such as corrosive actions or biological phenomena, potential degradation may occur over a considerable time period. In such cases, the design might not need to provide a high performance and durability of protective measures, as long as the items or parts of items subject to degradation can be inspected. The inspection regimes should have scope, periodicity and method commensurate with the degradation rates. The installed protective measures should also be capable of reapplication or else the design should permit treatment to inhibit, stop or reverse the degradation.

Interaction effects

4.39 EEs may cause direct damage to the facility: such effects are called 'primary effects'. In addition, they may cause indirect damage by means of interaction mechanisms that can propagate the damage ('secondary effects'). This indirect damage should be included in the analysis of the events as it may cause damage which could be comparable to or even exceed that caused by the primary effects. Secondary effects are explicitly addressed in the categorization of the items (EE category 2).

4.40 In the case of building structures designed against an external event, the design should address the following interaction effects to the nearby SSCs, caused by the event:

(a) Failure and collapse of nearby structures;
(b) Secondary missiles generated from nearby SSCs;
(c) Flooding from failure of liquid retaining structures, not necessarily close to the building;
(d) Chemical releases from failure of containers or deposits;
(e) Secondary fires or explosions, as a result of failures in tanks containing flammable or explosive material;
(f) Electromagnetic interference generated by electrical faults.

4.41 Special emphasis should be given to potential interaction effects between UHS components (e.g. failure of cooling towers and flooding from the UHS basin) and other safety related structures.

APPROACH TO STRUCTURAL ASSESSMENT FOR BEYOND DESIGN BASIS EXTERNAL EVENTS

General

4.42 The rules for design (DBEE) and the rules for assessment (BDBEE) are different. The purpose of the assessment should be to show that, reasonably, the BDBEE will not compromise the intended safety functions. For this purpose, the assessment for BDBEE should take credit for all safety margins intentionally or unintentionally introduced by the design process.

Loading derivation

4.43 For some external hazards, it may be possible to identify scenarios that are extremely unlikely yet still credible, which could be selected as the basis for the BDBEE. In these cases, the annual probability of exceedance of the BDBEE should correspond to about one order of magnitude less than that of the DBEE.

4.44 For some other external hazards, the approach above may lead to non-credible scenarios. In those cases, a 'hazard agnostic'[19] approach should be taken and the BDBEE may be selected by taking an adequate margin with respect to the DBEE. The BDBEE should challenge the structural design, especially when loading conditions could lead to cliff edge effects.

4.45 As done for the design loads, hazard parameters should be used as the basis for a set of beyond design parameters usable for the structural assessment. In the process, consistency with the hazard analysis should be maintained.

Load combinations and acceptance criteria

4.46 BDBEEs should be considered as a very infrequent event and corresponding loads should be combined only with normal operational loads using unity load combination factors.

4.47 BDBEEs are events for which widespread unrecoverable structural deformation within structures is acceptable. However, structural acceptance criteria should be established so that the performance of all fundamental safety functions is ensured.

Procedures for structural assessment

4.48 Procedures for structural assessment should normally be oriented to obtain realistic (median or best estimate) structural behavior.

Material properties

4.49 Material properties should be consistent with loading condition induced by EEs and realistic material in agreement with material specification, construction and quality assurance procedures associated with the safety category of the particular item. In structural assessment for BDBEEs, it is normally acceptable to use values less conservative than in design, for instance, reducing material safety coefficients or using values based on statistics of the results of tests performed on the actual materials used to build the structure.

[19] In this Safety Guide the term 'hazard agnostic' is used to indicate a situation where the protection against a hazard is provided without a complete knowledge of the size and frequency of the hazard. Generally, a standardized envelope design for external hazards constitutes a hazard agnostic approach.

5. SAFETY DESIGN PROVISIONS AGAINST EXTERNAL EVENTS

5.1. EXTERNAL FLOODS, INCLUDING TSUNAMI

5.1. SSG-18 [7] gives guidance for a site specific review of the potential risk of flooding of a site due to diverse initiating causes and scenarios (and relevant potential combinations). The phenomena that should be considered include:

- Storm surges;
- Wind generated waves;
- Tsunami;
- Seiches;
- Rivers and Streams flooding
- Extreme precipitation events
    - Local intense precipitation
- Floods due to the sudden release of impounded water
    - Dam failures
    - Ice dams
    - On site water storage for the UHS
- Bores and mechanically induced waves
- Channel migration
- High ground water levels

The phenomena are described in detail in SSG-18 [7], together with the methodology to derive the design bases conditions.

5.2. Scenarios that induce one or more of the following effects, including flood event duration, should be considered:

- Wind waves and run up effects;
- Hydrodynamic and other loading;
    - Hydrostatic load;
    - Hydrodynamic load;
    - Wave load;
    - Buoyancy load (vertical hydrostatic load);
    - Debris load;
    - Sediment load;
- Erosion and sediment deposition;
- Concurrent site conditions, including adverse weather conditions;
- Groundwater ingress;
    - Seepage and groundwater inflow;
    - Leakage;
- Other pertinent effects.

5.3. The design should consider potential damage to safety related SSCs by the infiltration of water into internal areas of the installation resulting in water pressure on walls and foundations that may challenge their structural capacity or stability. Groundwater may affect the stability of soil or backfill. Deficiencies or blockages in site drainage systems also could cause enhanced flooding of the site.

5.4. The design should consider the dynamic effects of water that can be damaging to the structures and foundations of a nuclear installation as well as to the many systems and components located on the site. Moreover, there may be erosion at the site boundaries, scouring around structures or internal erosion of backfill due to the effects of groundwater.

Parameters characterizing the hazard

5.5. The storm surge analysis should include estimates of static water elevation, or a distribution of water elevation with a corresponding annual frequency of exceedance, depending on the method used (i.e. deterministic or probabilistic).

5.6. The wind wave analysis should include estimates of the increases in water level due to wind wave activity and wave runup height along the beach and/or structures. In addition, relevant parameters (typically, wave kinematics) associated with dynamic effects of waves on plant structures should be considered. Loading and unloading analyses should include hydrodynamic effects, static loading effects, erosion and sedimentation, and other associated effects.

5.7. The tsunami flooding analysis should provide the maximum water level, event duration, runup height, inundation horizontal flood, backwater effects, minimum water level and duration of the drawdown below the intake. Loading and unloading analyses should include hydrodynamic effects, static loading effects, waterborne missiles, erosion and sedimentation, and other associated effects. The water level of the design basis flooding can be defined at a location or a series of locations off-shore where the linear long wave theory applies and reflected waves from the coast are not significant.

5.8. For the tsunamis induced by earthquakes in the vicinity of the site, uplift and subsidence of the Earth's surface should be taken into consideration in assessing potential negative impacts on the estimation of the water height in areas close to large earthquake rupture zones.

5.9. The seiche hazard should provide the maximum and minimum runup heights, duration, static loading effects, and hydrodynamic effects listed in para. 5.2.

5.10. The design for river flooding should consider flooding for an extended period of time, dam failure effects, and flood protection and navigation system operational effects. In an estuary, the design should consider combination of high tides, wave effects, high wind-driven water levels, and high-water level in the river.

5.11. The design should consider effects related to local precipitation flooding on site including, site grading, site and buildings drainage, sheet flow, and discharge on site from off-site areas. The design parameters should include flow rate and discharge time, peak water level and time history of water levels, and mean water velocity for evaluation of hydrodynamic forces, and potential sedimentation and erosion on the site.

5.12. Parameters to characterize floods due to the sudden release of impounded water should include the series of anticipated flow rates during the entire flood event, the peak water level at the site and the time-history of water surface elevation, the potential for intake blocking or damage, and the dynamic and static forces resulting from debris or ice, as well as other phenomena listed in para. 5.1. The parameters to characterize dam failure flooding should also include warning times.

5.13. Parameters describing bores and mechanical induced waves should include the maximum runup height, the associated duration, and the impact of the tidal fluctuation.

5.14. High ground water levels in the close vicinity of the site are generally consequence of another phenomenon, such as an increase of water level near river or sea, large intense precipitations or failure of water control structures. Parameters such as extreme ground water level and associated pressure on structures should be characterized.

5.15. Local precipitation flood applies to all sites. Other flood phenomena apply or not depending on site location, along a river, on sea or lake-shore or in an estuary. Paragraphs below provide guidance for these different cases.

5.16. The tidal water level range should be determined for all sites located in coastal, estuarine and river areas affected tides.

Design parameters

5.17. Design basis flood conditions should be derived based on SSG-18 [7]; these conditions result from one extreme event or, more often, from a combination of events. They are expressed in values of water level, water velocity, flow pattern, groundwater level and all the various combinations of events generating the flooding itself, as presented in paras 5.5–5.13. The action of water on the site protecting structures and on the plant structures may be static or dynamic, or there may be a combination of effects. In many cases the effect of ice and debris transported by the flood and the waves (or surge) are important variables in the evaluation of pressure.

5.18. SSCs important to safety should be protected from damage due to flooding. Design input at the point where SSCs important to safety are located should be determined from flooding effects at those locations. It should be taken into account that any local factors (such as site layout and topography, site grading, neighbouring structures, flow directions, intake structures and UHS configurations) might have an influence on the loading condition.

5.19. Hazards associated with low water levels and conditions and drawdown should be considered to address challenges to safety related systems including UHS. In some cases, an estimate may be necessary of the low flow rate and the low water level resulting from the most severe drought considered reasonably possible in the region. Causes of such conditions should include water evaporation, rainfall deficit, obstruction of channels, downstream failure of water control structures, and anthropogenic effects such as the pumping of groundwater. In other cases, a drawdown of the sea level may result from a surge, seiche or tsunami.

5.20. In the event of local extreme precipitation at the site, the drainage system is relied on and the design should include an adequate safety margin. Deficiencies or blockages in site drainage systems should be considered in flooding analysis.

MEANS OF PROTECTION

5.21. Nuclear installation should be protected against the design basis flood, including one or more of the following means of protection:

(a) The ’dry site’ approach described in para. 4.11, where plant elevation and all items important to safety are located above the design basis flood level with adequate margin;
(b) Implement engineered features to protect SSCs important to safety that could be affected by flood related water;
(c) Implement permanent barriers such as flood walls designed to prevent flood water from affecting SSCs important to safety;
(d) Implement protective measures such as breakwaters;
(e) Site grading and drainage systems;
(f) Install watertight doors and penetrations;
(g) Implement temporary watertight barriers, such as aqua dams, sandbags, inflatable berms, to be installed when necessary.

5.22. For new nuclear installations, equipment ultimately necessary to prevent an early radioactive release or a large radioactive release should be located at an elevation high enough above the design basis flood, or adequate engineered safety features (such as water tight doors) should be in place to protect this equipment and ensure that mitigating actions can be maintained.

5.23. For existing nuclear installations, the second option described in para. 5.22 is applicable.

5.24. When the ‘dry site’ concept cannot be applied to all items important to safety, the layout should include permanent flood barriers with appropriate design bases and adequate margin (e.g. hydrodynamic effects, impacts from floating objects, seismic qualification).

5.25. Civil engineering structures (e.g. sea walls) as permanent barriers for protecting SSCs important to safety against flooding should be properly designed to maintain their stability. The effects of flooding and other associated effects should be considered in assessing the potential failures of the structures.

5.26. Protection for openings (e.g. watertight doors) should be properly designed to maintain the function against the design basis loading conditions.

5.27. External barriers and natural or artificial plant islands should be considered features important to safety and should be designed, constructed and maintained accordingly.

5.28. If any filling is necessary to raise the installation above the level of the flood conditions for the design basis flood, this engineered plant item should be considered as an item important to safety and should therefore be adequately designed and maintained.

5.29. A warning system should be provided that is able to detect conditions indicating the potential for flooding of the site. When feasible, the response time should be sufficient to bring the installation to a safe condition together with the implementation of appropriate emergency procedures. Special operational procedures should be specified on the basis of the real-time monitoring data on the identified causes of the flooding.

5.30. Flood monitoring systems should be properly designed to withstand the design basis flooding. If necessary, protection of the monitoring systems from damage due to hydrodynamic forces and collisions of floating bodies should be considered.

COASTAL SITE

Loading

5.31. The following effects associated with design loading conditions should be considered:

- Run up
- Drawdown
- Hydrostatic and hydrodynamic and wave forces
- Buoyancy
- Collisions of floating bodies (e.g. logs, boats, barges)
- Erosion and deposition of sediments
- Aftershocks effects on flood protection and mitigation equipment.

It should be taken into account that associated phenomena, such as the movement of sand sediment, and collisions of floating debris, may simultaneously occur.

RIVER SITE

Loading

5.32. Design consideration for river floods should include similar loading phenomena, as appropriate, as a coastal site. Unique characteristics of river flooding should include potential duration of the flood event (weeks or months), dam failure effects, operational consideration of the dams and navigational system.

5.33. River floods in cold climates should be analysed for the formation of ice dams and transport of large ice floes or sediment and debris that could physically damage structures, obstruct water intakes or damage the water drainage system. Potential ice dam formation and failure can flood the site or create low water conditions.

ESTUARY SITE

Associated effects

5.34. The tidal water level range should be determined for those sites located in estuary areas affected by ocean tides.

Loading

5.35. Design consideration for estuary floods should include similar loading phenomena, as appropriate, as a coastal and a river site. Unique characteristics of estuary flooding should include combination of effects for river flooding and coastal flooding, for example combine effects of extreme high tides, wind wave, extreme precipitation, and river flooding.

ASSESSMENT FOR BEYOND DESIGN BASIS EXTERNAL FLOODS

5.36. Beyond design basis flooding is defined by increasing the design basis flood level and considering the appropriate combination of events to be considered with the flood.

5.37. For a new nuclear installation, SSCs ultimately necessary to prevent an early radioactive release or a large radioactive release should either be located at an elevation high enough above the beyond design basis flood or should have adequate engineered features to protect these SSCs and ensure that mitigating actions can be maintained.

5.38. For existing nuclear installations, the second option described in para. 5.37 is applicable.

5.2. EXTREME WINDS

INTERFACE WITH HAZARD ASSESSMENT

5.39. SSG-18 [7] provides general guidance on assessing the extreme winds hazard. The document covers strong ‘straight’ winds, tropical cyclones (typhoons and hurricanes), and tornadoes. For the purposes of this section, the output of interest from the wind hazard analysis is the hazard curves for wind speed (median, mean and fractiles or discrete family of curves) in open terrain and at a specified height, usually 10 m above ground level.

5.40. The results of the hazard study are used to define the design basis wind (DBEE), which is normally specified as a design wind speed. The reference values for design wind speed should be consistent with the selected design basis external event policy[20] of the regulatory body.

[20] In some Member States, the design extreme wind speed is chosen with a 100-year return period (1% annual probability of exceedance), whereas design rare events causing high winds (tornado, typhoon) are typically chosen with a much longer return period.

5.41. Wind speeds should be averaged over definite time periods. Time averaging of wind speed should be done using time periods consistent with natural frequencies found in SSCs[21]. In addition, corrections for local topographical effects, if any, should be considered.

5.42. For some sites, in addition to design wind speeds corresponding to 'extreme' meteorological phenomena, 'rare' meteorological phenomena, such as tornadoes and hurricanes [7] should also be considered. In design, the former is usually considered as an extreme condition and the latter, as a rare condition.

5.43. Unless there is a clear evidence for a preferred direction of extreme winds, the wind at the design speed should normally be assumed to blow from any direction.

5.44. Beyond design basis wind speeds (BDBEE) should be established at an appropriate annual probability of exceedance less than that of the DBEE.

LOADING

5.45. Structural loading derived from the wind speed and duration should be obtained in the form of pressure or suction on surfaces exposed to wind.

5.46. The actual wind forces depend on the structural shapes and, in regular practice, they should be determined from the wind velocity using shape factors. The vertical distribution of wind velocity should also be considered.

5.47. Wind loads can normally be treated as static loads for structures normally designed and built in nuclear installations. Dynamic structural effects are usually considered for structures whose natural frequencies are smaller than 1 Hz.

5.48. It should be noted that the wind acting upon the plant buildings is not the free field wind. Interference effects, such as sheltering by other buildings or Venturi effects in passages between buildings, when present, may have a strong influence in the wind generated pressures. For example, shielding effects of various structures at the site can result in an increase of wind speed through a constricted space or a decrease, where it may be slowed down due to obstructions. Such funnelling characteristics describing the channelling of winds around structures may have a very important influence on the wind forces. High winds have been known to cause collapse of cooling towers as a consequence of a 'group effect', even though they were individually designed to withstand an even higher wind speed. These effects should be considered in the design.

5.49. The combinations of wind induced loads with other design loads may vary depending on the origin of the wind. It is common practice to use larger load factors for straight extreme wind loads than for wind loads derived from rare meteorological phenomena (e.g. hurricanes and tornadoes). In the case of (rotational) wind due to tornadoes, the direction of wind on one surface of a structure could be different to (including the opposite of) the direction of wind on another

[21] For structural design in nuclear installations, time averages over 1 to 3 seconds (gust speeds) are usually necessary.

surface. Design should consider such loading conditions specific to rotational wind due to tornadoes.

DESIGN AND QUALIFICATION METHODS

Local response

5.50. The first set of failure modes that should be considered correspond to local structural failures at the surfaces directly exposed to wind pressure or suction forces. These include portions of the building enclosure (walls, façade panels, roof panels, doors) used to transfer the wind loads to the building's main structural system. This type of local structural failure is the most commonly observed during strong wind events. Typically, these failures do not cause a major collapse, but they might affect the components located in the immediate vicinity of the failure and, in addition, produce a change in the ambient pressures within the building. Wind capacity analysis for these failure modes should be performed, which usually involves assessment of structural capacity of the enclosure elements themselves and the assessment of mechanical capacity of the connection to the main structural system.

5.51. In analysing the failure of equipment within the buildings, the design should conservatively assume that a failure in the enclosure causes the failure of all sensitive equipment protected by the failed portion of the enclosure.

Global response

5.52. The second set of failure modes that should be considered corresponds to the global failure or global instability of the main structural system of the buildings under the wind loads. These failures would be able to produce a major collapse of the building. Wind capacity analysis for global failure modes should consider the assessment of structural capacity of the main structural system under the wind loads. With regard to the global response, dynamic effects can usually be neglected when natural frequencies are larger than 1 Hz.

Impact by windborne missiles

5.53. The aerodynamic forces produced by extreme winds can accelerate objects and produce missiles that impact structures and components. The resulting impact loads constitute one of the principal loading effects of extreme winds and they should be considered in the design.

5.54. Windborne missile analysis should be performed to identify the potential missiles. It usually follows a deterministic approach. The approach uses a spectrum of several missile types and maximum velocities to be considered. It should be ensured that administrative procedures are continuously effective for them to be credited for reducing the spectrum of missile types to be considered.

5.55. Missile impact effects include local response (penetration, perforation, and spall) and overall response of the impacted structural member (such as dynamic shear effects at the edge supports of the impacted wall). Local response effects should be estimated taking into account the missile type and target materials. Overall response, when relevant, should be analysed through dynamic analysis considering deformation of the missile or a given impact force time history.

5.56. The velocity and orientation of the missile are important input parameters to determine missile impact effects. In general, the missile impact should be assumed to have a velocity vector normal to the target surface and a missile axis collinear with the velocity vector.

Atmospheric pressure changes

5.57. Atmospheric pressure change loadings result from the variation in the atmospheric pressure field as a vortex moves over a structure. Atmospheric pressure change loads should be considered especially for tornadoes, where there exists a combination of relatively high translational storm speed and a significant pressure drop in the centre of a rapidly rotating vortex.

5.58. The estimation of atmospheric pressure change loads should be done using a model of the tornado wind field and the knowledge of the rate at which the structure may vent.

Dust and sand storms

5.59. For the design against dust and sand storms, in addition to the associated wind speeds, the hazard analysis team should be informed to provide additional parameters such as the duration of the storm and the expected dust and sand loading of the air during the storm (mg/m^3).

5.60. The design against sand and dust storms should take into account the following aspects:

(a) Increase of the effective air density, which produces larger wind pressures on the exposed surfaces;
(b) Dust and sand accumulation effects, which could increase gravity loads on roofs and horizontal thrust on walls and could block access routes;
(c) Potential clogging of filters at air intakes for heating ventilation and air conditioning systems or emergency diesel generators;
(d) Abrasive and corrosive effects in equipment, especially in the long term;
(e) Functionality of radiation monitoring during dust and sand storms;
(f) On-site management and communications under reduced visibility conditions.
(g) Sand deposition in the UHS.

Miscellaneous

5.61. Wind can affect the structural integrity of SSCs but can also be the root cause of effects that should be considered during design. Examples are as follows:

- Pressure differentials could affect the ventilation system;
- Particles carried by the wind could damage exposed surfaces and prevent the functioning of components and equipment;
- Salt water spray could jeopardize the functionality of electrical equipment.

5.62. The UHS and its directly associated transport systems should be evaluated to ensure that any changes in water level caused by an extreme wind cannot prevent the transport and absorption of residual heat. Credible combinations of effects should be considered when appropriate.

5.63. The spatial systems interaction effects from wind on safety related structures could be of concern; for instance, collapse of heavy and high rising cranes parked outside the containment and other important to safety structures, as well as chimneys, and cooling towers. A dedicated analysis should be performed and adequate mitigation methods, such as physical separation or protective structures, should be provided, if necessary.

MEANS OF PROTECTION

5.64. For wind hazards, the building structures normally designed for nuclear installations provide a good level of protection for items important to safety. Hence, from the perspective of design against wind effects, it is a good practice to locate as many items important to safety inside the buildings and to leave as few as possible of these items exposed to the outside environment.

5.65. Sensitive items important to safety located outside the buildings should be protected against windborne missiles. Sensitive items include components such as instrumentation, small pipe and tubing, glass or ceramic pieces, dials and gauges, exposed belts, chains or couplings on motors. Level of protection should be consistent with the spectrum of missile types and maximum velocities considered in the design. As a means of protection, adequate immobilization of equipment or materials outside could be also effective to prevent generating windborne missile.

ASSESSMENT FOR BEYOND DESIGN CONDITIONS

5.66. Assessment for beyond design basis wind (BDBEE) should be performed for SSCs that are used for the containment of radioactive material or otherwise mitigation of the consequences of an accident caused by extreme winds or associated hazards.

5.67. Methods in the assessment for beyond design basis wind (BDBEE) should normally be the same as in the design for design basis wind (DBEE). The differences should be reflected in the acceptance criteria and the material properties used in the assessment (see Section 4).

5.3. OTHER EXTREME METEOROLOGICAL CONDITIONS

5.68. SSG-18 [7] provides guidance for a site specific review of extreme meteorological events, grouping natural hazards as follows:

- Extreme air and water temperature;
- Extreme atmospheric moisture;
- Snow precipitation (also blizzards), freezing rain and ice pack;
- Lightning.

Other hazards may be connected with these, such as frazil ice, frost and hail.

5.69. Damage due to the hazards described in para. 5.58 is usually represented by the unavailability of the power supply or the electrical grid, but some hazards such as snow could also affect ventilation intakes and discharges, structural loading, ventilation and diesel generator combustion air intakes, access by the operator to external safety related facilities and mobility of emergency vehicles. Extreme air or water temperature could affect the heating, ventilation and air-conditioning systems of rooms housing systems important to safety (especially electronic equipment) and the availability of the UHS. These should be considered in design and safety analysis of the installation.

5.70. Damage that may be caused by lightning has been shown to be very extensive and therefore protection from lightning should be taken into consideration.

LOADING

5.71. The hazard analysis team related to the above-mentioned EEs should be informed that the necessary definition of the environmental parameters follows the evaluation of the extreme values for the quantities of interest. Needed parameters also include the duration of such conditions, their periodicity and their reasonable combination with other load cases, such as wind or precipitation, and biological conditions.

DESIGN METHODS AND MEANS OF PROTECTION

5.72. Unless special national codes and standards are available for the design of nuclear installations in relation to these hazards, structural design should follow the codes and standards for conventional buildings, while equipment should be qualified in accordance with its safety and EE classification.

5.73. Special protection from lightning should be designed and implemented, with periodic assessment of the dedicated protection means following international industrial standards, special national codes and standards or qualified modelling. In general, a comprehensive Faraday cage should be put in place by means of narrow mesh thin reinforcing bars in the outer skin of the building walls. Moreover, special care should be taken in the protection of conductors at short distances from each other and/or protruding from the cage protected volume.

5.74. Intake structures for the heat transport systems directly associated with the UHS should be designed to provide an adequate flow of cooling water during seasonal water level fluctuations, as well as under drought conditions.

5.75. Due allowance should be made for the effects of extreme weather conditions on make-up supplies, even when these do not necessitate any extensive off-site capability. Thus, such aspects as freezing of supply pipework should be considered and trace heating provided where appropriate.

5.76. Measures should be taken, by testing and/or analysis, to confirm that the facilities provided to reject heat to the UHS still retain their capability under extreme meteorological conditions, particularly if there are long periods when the facilities are not used. These measures would include, for example, monitoring the operability of spray nozzles to check that they do not become blocked frozen or intake screens to check that they do not blocked by ice. To prevent service water blockage due to frazil ice, measures to prevent frazil ice formation (outlet water recirculation to intakes, bar screen heating) and alternative path(s) for cooling water intake should be provided. Alternative path(s) for water cooling should be provided to counter the formation of frazil ice at the service water intake, if justified by site conditions. In this case, provision should be made for adequate instrumentation and alarms and relevant procedures and training.

ASSESSMENT FOR BEYOND DESIGN CONDITIONS

5.77. Beyond design basis for other meteorological events should be considered taking into account predictions of climate change that may affect the design basis parameters already considered.

5.4. VOLCANISM

5.78. Recommendations related to the evaluation of hazards related to volcanoes are provided in SSG-21 [8]. Table 1 of SSG-21 [8] comprises a list of phenomena that may be associated with volcanoes together with their potentially adverse characteristics for nuclear installations. The nuclear installation should be protected against all volcano related hazards that have been identified based on the list of phenomena in Table 1 of SSG-21 [8].

5.79. It should be reconfirmed that adequate measures are available for all the identified phenomena associated with volcanoes as a result of hazard evaluation.

5.80. In general, phenomena such as pyroclastic flows, lava flows, opening of new vents and ground deformation (including debris avalanches) are considered to be exclusionary. If these phenomena have not been screened out during the hazard evaluation stage, criteria related to the acceptability of any protection measures should be discussed with the regulatory body.

DESIGN METHODS AND MEANS OF PROTECTION

5.81. The design envelope of the nuclear installation for external hazards may provide sufficient protection against some of the volcano related effects. This should be verified for each individual effect using adequate safety factors in order to account for uncertainties.

5.82. If the volcano related effects are not bounded by the external hazard design envelope of the nuclear installation, then design features or site protection measures should be provided.

5.83. Tephra fallout may have two consequences both of which should be considered, because this fallout could result in static physical loads and abrasive and corrosive particles in air and water. The additional gravity loads on horizontal surfaces should be appropriately combined with other vertical loads. Tephra may also cause disruption of safety related SSCs by entering into orifices such as exhausts and intakes similar to sand and dust storms. Appropriate measures should be taken against these phenomena.

5.84. As mentioned in para. 5.80, massive flows, such as, lava flows, pyroclastic flows, lahars and debris avalanches, are considered exclusionary and should normally be screened out in the site selection process. There is no credible precedent for design or site protection measures against these phenomena in nuclear installation related applications. Protective barriers may be considered if the nuclear installation is sufficiently distant from the volcano, so the flow is substantially decreased and if design bases have been established for these effects in terms of parameters such as volume, velocity, temperature and viscosity. In such cases all uncertainties should be considered, and large safety factors should be used in the design of these protective structures. In any case, solutions and measures should be discussed with the regulatory body on a case by case basis.

5.85. Volcano generated missiles generally affect a limited area around the volcano and the nuclear installation site should be selected to be outside of this zone. Design bases should be derived for missiles that may possibly reach the site with low probability. The effects of these missiles should be compared with other missiles such as tornado or wind borne missiles and aircraft crash. Both impact and potential fire hazards should be considered. Parameters that should be obtained from the hazard analyst should include mass, terminal velocity and temperature.

5.86. If hazard from this missile effect has been identified and a design basis has been derived, then design features and procedural measures should be provided. Parameters that should be obtained from the hazard analyst include the type of gas (including all physical and chemical properties) and its concentration when it arrives at safety related SSCs including the control room.

5.87. Volcano induced flooding should be considered and coordination with flood protection experts should be established. Flooding induced by volcanic activity may affect both coastal and inland sites. Tsunamis and seiches should be considered for coastal sites however crater lake failures and glacial burst might affect any site, coastal or inland. Parameters that should be obtained from the hazard analyst are similar to those for floods from all other causes.

5.88. Volcanic earthquakes should be considered in the seismic hazard analysis for the nuclear installation. If volcanic seismic hazards at the site are not lower than those associated with other sources of seismic activity, ground motion from volcanoes should be assessed.

DESIGN BASIS AND BEYOND DESIGN CONDITIONS

5.89. Non-exclusionary aspects related to volcanic hazards should be treated as DBEE loads. If any of the potentially exclusionary aspects cannot be adequately screened out with sufficient margins, these should, with the agreement of the regulatory body, be treated in the framework of BDBEE.

5.5. EXTERNAL FIRE

5.90. Fire that originates nearby the site (such as from fuel storage, vehicles, and other transportation sources including roadways, waterways, and airways, as well as pipelines, chemical processing and manufacturing facilities bushes, peat and wood) may have safety significance.

Precautionary measures should be taken to reduce the amount of combustibles in the vicinity of the plant and near access routes, or else adequate protection barriers should be installed. For example, vegetation that could propagate a fire in close proximity to the plant should be removed. A specific analysis for coastal sites should consider the potential for burning oil spilled into the sea (by a stricken vessel or an extraction platform). If necessary, appropriate measures for establishing an exclusion zone should be taken. A detailed discussion is provided in NS-G-3.1 [9].

5.91. At sites for which an aircraft crash scenario is postulated, the crash event is generally associated with the release of significant amounts of fuel, most of which will probably be ignited, and this may lead to subsequent explosions. The design measures for such an event generally envelop the provisions necessary to handle other external fire scenarios as mentioned above. Such fires should be taken into consideration in line with recommendations provided in para. 5.90.

5.92. The nuclear installation design should prevent smoke or heat from fires of external origin from impairing the accomplishment of necessary safety functions and from impairing the stability of safety related structures at the site.

5.93. The ventilation system might be affected by smoke or heat. It should be designed to prevent smoke and heat from affecting redundant divisions of safety systems and causing the loss of a necessary safety function (including operator action).

5.94. Diesel generators usually need air for combustion. The nuclear installation design should ensure an adequate supply of air to all diesel generators that are needed to perform necessary safety functions.

5.95. Where the site of a nuclear installation requires consideration of the effects of an aircraft crash at or near the site, a fire hazard analysis of such an event should be made. Fires that may occur at several locations because of the spreading of the aircraft's fuel should be considered in this analysis. Smoke may also be produced at several locations. Special equipment such as foam generators and entrenching tools as well as specially trained on-site and off-site firefighting personnel may be used to prevent such fires from penetrating structures containing items important to safety (see para. 5.199).

LOADING

5.96. The fire hazard analysis team should be informed that the characteristics of the postulated fire to be modelled include radiant energy, flame area and flame shape, view factor from the target, speed of propagation and duration. Secondary effects such as spreading of smoke and gases should also be specified.

5.97. The effects of an external fire originating from sources such as fuel storage, vehicles, bushes, peat or wood should be combined with normal operating loads. Fires as a consequence of scenarios such as an aircraft crash should be considered in the same load combination and with the same design assumptions (as for the initiating event itself).

DESIGN METHODS

5.98. The vulnerability of structures to the thermal environments arising from large external fires should be assessed against the inherent capacity of the envelope of the structures to withstand such environmental conditions. The verification should be based on the capacity of the material to absorb thermal loads without exceeding the appropriate structural design criteria. The capacity of concrete to resist fires is mainly based on the thickness, the composition of aggregates, the reinforcing steel cover and the limiting temperature at the interior surface[22]. The limiting structural criteria may be the temperature at the location of the first reinforcing steel bar and the ablation of the surface exposed to the fire.

5.99. Reinforced concrete structures designed to carry impact loads resulting from an aircraft crash are generally strong enough to resist failures of structural elements that relate to external fire scenarios. In general, the capacity of steel structures exposed to large fires is limited. Therefore, structures that have safety functions should not be constructed using steel as load bearing elements. If the fire resistance of steel structures relies on separation from external cladding or any applied intumescent cooling, for example, it should be verified that such an improvement in fire protection is not endangered by secondary effects potentially associated with the fire scenario (e.g. explosion pressure waves and missiles).

5.100. Other criteria concerning the interior face and the room air temperature should be assessed in order to protect items important to safety housed in the affected rooms. These criteria are usually not exceeded if sufficient thickness is provided to satisfy other considerations. Design penetrations of all types should also be checked.

5.101. In some cases where thick concrete walls or slabs are exposed to fire, a structural analysis should be carried out with the temperature gradient due to fire plus any additional operating loads under fire conditions (e.g. extinguishing water). In accordance with extreme load conditions the load factor of unity may be used under ultimate load design for postulated fire loading conditions. National codes and standards provide guidance on fire hazards and fire resistance of materials subjected to flame, heat, and other phenomena.

MEANS OF PROTECTION

5.102. Protection of the plant against external fires initiated outside the site may be achieved by minimizing the probability of a fire and by strengthening the barriers against external fires when necessary. Other design characteristics, such as redundancy of safety systems, physical separation by distance, by separate fire compartments or by specific barriers, and the use of fire detection and extinguishing systems should also be provided.

5.103. If the inherent capacity of the structure does not suffice, an additional barrier or distance separation should be provided. Additionally, heat resistant cladding or tumescent coatings could be used to provide further protection for structural elements. However, it should be verified that

[22] Special care should be taken with regard to the resistance of high strength concrete in fire scenarios.

such improvements are not endangered by secondary effects potentially associated with the fire scenario (e.g. explosion pressure waves, heat fluxes and generated missiles).

5.104. The ventilation system should be protected by isolation of the systems from outside air by means of dampers with reliance on alternative systems to accomplish the functions of the ventilation system. This can also be achieved by separating the inlet and exhaust hoods of one ventilation system serving one safety system from the inlet and exhaust hoods serving other redundant safety systems. Thus, a fire of external origin should not prevent the performance of a necessary safety function.

5.105. The nuclear installation design should ensure an adequate supply of air to all diesel generators needed to perform necessary safety functions. This objective should be met by segregating the air intakes and separating them by distance.

5.106. Safety related cables, instrumentation and control systems, which have been demonstrated to be particularly exposed and vulnerable to heat flux, smoke and dust, should be qualified for such a scenario.

ASSESSMENT FOR BEYOND DESIGN BASIS EXTERNAL FIRE

5.107. Extreme yard fires that have the potential to affect several safety related structures including the containment (e.g. caused by the fuel spillage from a large airplane crash), should be treated within the framework of BDBEE.

5.6. EXTERNAL EXPLOSIONS

5.108. The word 'explosion' is used in this Safety Guide in a general way, to designate all chemical reactions involving solid, liquid, vapour or gas, that may cause a substantial pressure rise in the surrounding space and, possibly, fire or heat. Explosions of gas or vapour clouds can affect the entire installation area. An analysis of the ability of installation structures to resist the effects of a gas cloud explosion should be performed in order to assess their capacity to withstand the overpressure (direct and drag) loading. However, other possible effects should also be considered: fire, heat flux, smoke and heated gases, ground and other vibratory motions, and missiles resulting from the explosion.

5.109. In general, the following effects of explosions should be considered when analysing installation response:

- incident and reflected pressure;
- time dependence of overpressure and drag pressure;
- blast generated missiles;
- blast induced ground motion (mainly from detonation);
- heat and/or fire.

5.110. If the installation has been designed to accommodate the effects of externally generated missiles resulting from other events such as a hurricane, typhoon, tornado or aircraft crash, the effects of missiles generated by an explosion may already have been taken into account. However, if particularly threatening missiles produced by explosions can be identified, they should be considered in the installation design. If missiles from an aircraft crash or natural phenomena are not included in the design basis, potential blast generated missiles should be considered.

INTERFACE WITH HAZARD ASSESSMENT

5.111. Explosions during the processing, handling, transport or storage of potentially explosive substances outside the safety related buildings should be considered in the site hazard assessment, in accordance with NS-G-3.1 [9] The explosion hazard can come from stationary or mobile sources. The result of the explosion hazard assessment should include a list of potential explosion sources with an associated amount and nature of the explosive substance, the distance to the site, and the direction from source to site. Occasionally, the annual frequency of explosion for each source is also given.

5.112. Design basis parameters should be determined using one of the following methods so as to protect the nuclear installation against unacceptable damage by pressure waves from detonations:

(1) If there is a potential source in the vicinity of the plant that can produce a pressure wave postulated external event, as determined in SSG-18 [7], propagation of the wave to the installation should be calculated and the resulting pressure wave and associated drag force should be the basis for the design.
(2) If there is already a design requirement to provide protection against other events (such as tornadoes), a threshold value should be calculated for the corresponding overpressure. This value allows the calculation of safe distances (stand-off distances) between the installation and any potential source.

5.113. Beyond design basis explosions (BDBEE) should be established by increasing the amount of explosive substances and/or reducing the stand-off distances with respect to the design values (DBEE).

LOADING

5.114. Detonations in explosives are characterized by a sharp rise in pressure which expands from the centre of the detonation as a pressure wave impulse at or above the speed of sound in the transmission media. It is followed by a much lower amplitude negative pressure impulse, which is usually ignored in the design, and it is accompanied by a dynamic wind caused by air behind the pressure wave moving in the direction of the wave.

5.115. Unlike the detonation of solid explosives, liquid, vapour and gaseous explosive materials exhibit a considerable variation of their blast pressure output. An explosion of such materials is in many cases incomplete, and only a portion of the total mass of the explosive (the effective charge weight) should be considered in relation to the denotation process. A conservative estimate should be made for the portion of the total mass assumed to detonate.

5.116. A deflagration normally results in a slow increase in pressure at the wave front and has a longer duration relative to a detonation, with the peak pressure decreasing relatively slowly with distance. The rate of decrease of overpressure with distance of travel differs between deflagration and detonation. Near the source, peak overpressure from detonation decreases quickly with distance. These characteristics, in addition to being functions of the propagation distance, are also influenced by the weather conditions (e.g., temperature inversion) and the topography, which should all be considered. A major difference between deflagrations and detonations is the heat or fire load on the target structure. In general, the heat or fire load from a detonation is not considered a part of the design basis for a target structure but should be considered for a deflagration.

5.117. Loads and heat effects derived from accidental explosions should be combined with normal operation loads only.

Detonation

5.118. Blast pressure loading from explosions should be determined using one of the various techniques available in the engineering practice, mainly developed for hazard studies for chemical plants: TNT equivalent, multi-energy methods, the Baker-Strehlow method and computational fluid dynamics. In the case of solid detonation, the TNT equivalent technique is the most widely used approach. In the case of a gas or vapour cloud, the elevation of the explosion and the reaction characteristics may suggest other approaches.

5.119. For the purposes of structural design or assessment, the variation or decline of both the incident blast wave and dynamic wind pressures with time should be considered, since the response of a structure subjected to a blast loading depends upon the time history of the loading as well as the dynamic response characteristics of the structure.

Deflagration

5.120. Deflagration loadings are not as well defined as detonation loads. Deflagration loading should be obtained using the same procedures as for detonation loading but taking an appropriately conservative reduced mass of deflagrating material.

5.121. Fire should be considered as a secondary effect of the deflagration. In this respect, the recommendations in paras. 5.90–5.107 and in NS-G-1.7 [10] should be followed.

DESIGN AND QUALIFICATION METHODS

Design for postulated explosion effects

5.122. Protection against the effects of an external explosion can be ensured by designing structures to withstand detonation or deflagration explosion effects. Design should involve the following steps:

(a) Characterize the blast pressure and dynamic (wind) pressure acting on the structure, including any reflection due to orientation of the walls. For design, the time history of the pressure is needed.

(b) Obtain forces acting on the external surfaces of the structure;

(c) Determine the structure's resistance to the pattern of forces, assuming elastic or elastic-plastic behaviour. Resistance depends on acceptance criteria, defined in terms of material strain limits and structural deformation limits. It is common that overall resistance is governed by local failures (e.g. exterior wall panels).

(d) Compute the structural response to forces obtained in (b). Computation can be done using simplified models (e.g. single degree of freedom models) or complex models (e.g. non-linear finite element computations). In any case, even when using quasi-static computations, consideration of the dynamic nature of the loading and the structural response is mandatory. Note that the effective loads on structures due to blast and associated dynamic wind loads are a function not only of the dynamic characteristics of the load but also the dynamic response characteristics of the structure,

(e) Compare structural response with structural resistance and modify design, if necessary. In performing the comparison, structural resistance in (c) might need to be reduced to account for the structural capacity necessary to sustain normal operation loads.

(f) Check the ability of the main structural system to carry loads transferred from the exterior surfaces directly receiving the explosion loads, in case the main structural system is not included in the model used to compute the structural response in (d).

(g) Check the overturning and sliding stability of the structure.

The following paragraphs elaborate on some of these steps.

5.123. Minimum parameters to define the response of a particular structure should include the duration of the load and the natural period of the structural response, as well as the damping and maximum level of ductility exhibited by the structure during the response.

5.124. In evaluating the blast effects, a distinction should be made between the local and global response of buildings. The local response is associated with response of external wall elements relative to their supporting members (girt, purlin, beam and column). The global response is typically associated with the primary load carrying system, which normally includes frames, beams, columns, diagonal bracing, shear walls and floor diaphragms.

5.125. External wall or roof elements, directly exposed to explosion loads should be explicitly assessed based on their local response.

5.126. For global structural elements, which make up the primary load path for the structure, the peaks of load are clipped by the elastic-plastic behaviour of the external elements directly exposed to the explosion. For these cases, simplified approaches to check the ability of the primary load path to carry loads transferred from the exterior surfaces can normally be used, if justified.

5.127. Vibratory loads induced into the building structures by the explosion should be evaluated and, if significant, the relevant response spectra should be calculated for the dynamic design of components and equipment, in accordance with their external event classification.

5.128. Direct and indirect effects of the explosion on the air supply and ventilation systems should be assessed. Even if the systems are inside a structure, the analysis should verify that the ducts are not damaged by the pressure wave to the extent that the safety function cannot be accomplished, and that any dampers in the air and ventilation systems perform their required safety functions.

Design for stand-off distance

5.129. Protection against the effects of an external explosion can also be ensured by a suitable stand-off distance between the explosion source and the target SSC. The difference with the safe distance studies performed in the site hazard assessment described in NS-G-3.1 [9] is that now the layout of the plant is known, and pre-proportioning of structures has been made. Therefore, at the design stage, safe distances should be verified based on more accurate information.

5.130. When calculating distances necessary to provide protection by means of separation, the attenuation of peak overpressure and heat as a function of distance from the explosion source should be used. The data available for TNT can reasonably be used for other solid substances by using the appropriate TNT equivalence. The adequacy of the protection afforded should be evaluated carefully for mobile sources on transport routes in the site vicinity. A sufficient number of plausible locations for the explosion should be postulated in accordance with NS-G-3.1 [9] to ensure that the worst credible situation has been analysed.

MEANS OF PROTECTION

5.131. Shielding structures other than buildings should be considered in the protection against blast wave loading and heat. Such structures are most useful for protecting against explosions generated by vessel ruptures or detonations, as their main advantage is to provide missile protection to the buildings (in which case they should intercept the missile's trajectory) and explosion overpressure protection (in which case the barrier should be close to the protected building to avoid pressure refraction behind the wall).

5.132. The protective measures that should be considered in design include adding supporting members to increase resistance and reduce unsupported spans, using strong backing walls for increased resistance, through bolting of walls to roofs, floors and intersecting walls to improve overall structural integrity, and replacing or reinforcing doors and windows with blast resistant elements. Safety important air intakes should be provided with automatic pressure wave protection shutters.

ASSESSMENT FOR BEYOND DESIGN CONDITIONS

5.133. Methods in the assessment for beyond design basis explosion (BDBEE) should normally be the same as in the design for design basis explosion (DBEE). The differences are in the acceptance criteria and the material properties used in the assessment (see Section 4).

5.7. ASPHYXIANT, TOXIC GASES, TOXIC AND CORROSIVE CHEMICALS AND FLAMMABLE VAPOUR CLOUDS

5.134. Asphyxiant and toxic gases might on release affect the nuclear installation both externally and internally, damaging or impairing safety related systems and operator action. Corrosive gases or liquids released might potentially enter and damage the plant cooling system. Additionally, fluids from oil spills or corroded pipes might adversely affect the function of heat exchangers, pumps and valves, potentially affecting safety related items. Corrosive fluids might also affect outside areas, such as switchyards, and consideration should also be given to outside electrical and electronic equipment.

INTERFACE WITH HAZARD ASSESSMENT

5.135. NS-G-3.1 [9] addresses the hazard assessment of release of hazardous fluids at or near the installation. The release hazard can come from stationary or mobile sources. The result of the release hazard assessment should be a list of potential release sources including their characteristics (form of release, location of release, amount and nature of the hazardous substance). When the hazard cannot be screened out based on safe distance or probabilistic considerations, the outcome of the hazard study should be used to characterize the releases to be included in the design bases against hazardous releases.

5.136. Beyond design basis releases (BDBEE) should be established by increasing the amount of substances and/or reducing the distances with respect to the design values (DBEE).

DISPERSION

5.137. After characterizing the release to be used for design, atmospheric transport of the released gas should be calculated by means of a dispersion-diffusion model that allows for temporal and spatial variation in the release parameters and concentrations.

5.138. Many atmospheric dispersion models have been developed over the past years and even complex computational fluid dynamics modelling has been used for scenarios involving hilly terrain. The most common practice uses Gaussian plume models, for continuous releases, or ‘puff’ dispersion models with a Gaussian concentration distribution within the plume, for quasi-instantaneous and short-term releases. As a minimum, the model should account for longitudinal, lateral and vertical dispersion of the release.

5.139. Calculation of dispersion should consider many scenarios, linked to the time distribution of meteorological conditions at the site: wind speed, atmospheric stability, wind direction, insolation and cloudiness. The goal should be to obtain the statistics of dilution factors[23] between the release point and the relevant locations in the plant, usually the air intakes of buildings.

5.140. Toxic and asphyxiant gases may be heavier or lighter than air. In boil-offs and slow leaks, the effects of density on vertical diffusion should be considered when adequately supported by experimental data or numerical simulation. However, the density effect of heavier-than-air gases should not be considered when turbulence effects are dominant versus buoyancy effects (e.g. when a release is the result of a burst or when the released material goes into the turbulent air near buildings). Special consideration should be given to heavy gas clouds formed by cold gas-air mixtures (such as liquid $NH_{3\text{-air}}$) which could travel far without being dispersed by atmospheric turbulence.

DESIGN AND QUALIFICATION METHODS

5.141. Once a toxic or asphyxiant gas cloud has been postulated, dispersion calculations should be carried out to estimate the gas concentrations as the cloud drifts or flows across the installation site.

5.142. In design, airflows during both normal and exceptional conditions should be considered, together with the volumes of all rooms sharing one ventilation system and the volume of the ventilation systems itself.

5.143. To simplify the calculation, it can be assumed that the concentration in the cloud remains constant during the interaction time with the affected air intake. Furthermore, the same gas concentrations in all rooms sharing one ventilation system may be assumed. These assumptions are conservative regarding estimates of gas concentration but not for estimates of recirculation time or for determining the amount of bottled air supplies necessary; for this purpose, a more refined analysis should be carried out.

5.144. In some designs, the ambient air in certain rooms becomes isolated from potentially contaminated air after an accidental release. In those cases, the in-leakage rate of the isolated environment becomes critical for the estimation of times until reaching hazardous concentration levels. These in-leakage rates considered in the calculations should be confirmed by testing in the constructed system, functioning under the same conditions as assumed in the design bases.

5.145. When credit is given in the evaluation to the removal of chemicals by filtration, adsorption, or other equivalent means, the technical basis for the removal capability should be included by the analysts in the design documentation.

[23] Dispersion is usually expressed in relative terms with respect to the source of the release. For example, it can be expressed as the average effluent concentration at a point divided by the release rate at the source or divided by the effluent concentration at the source.

5.146. Once concentrations inside buildings have been determined, they should be compared with the toxicity limits established in the Member State, to assess consequences to humans, or with equipment specifications, to assess effects on equipment performance.

MEANS OF PROTECTION

5.147. Given a known source of toxic or asphyxiant gases, gas detectors able to detect these gases at control room air intakes should be provided. When gas concentrations exceed the prescribed levels, protective actions should be initiated with due regard to quick acting materials such as chlorine gas. These actions should include filtering the incoming air, prevention of ingress of air during the critical time period by use of recirculation air systems and use of self-contained breathing apparatus.

5.148. The control room and its emergency ventilation system should have a low-leakage design.

5.149. Some types of toxic or asphyxiant gas, such as those that might be released along traffic routes (such as on land, sea, rivers and railways), cannot be identified in advance. Although the provision of detectors capable of detecting all types of toxic or asphyxiant gas is not practical where multiple sources of gases could be a hazard, consideration should be given to providing detectors that would be as versatile as practicable (capable of detecting groups of gases such as halogens or hydrocarbons) and which are also able to detect a decrease in oxygen levels.

5.150. For NPPs, the supplementary control room, which is remote from the main control room and with a separate air supply from dedicated air intakes, should be designed to provide a location for shutting down and monitoring the reactor. The routing from the main control room to the supplementary control room should be protected to allow for the movement of the operators, or alternative arrangements should be made for personnel access via a control point at which a breathing apparatus is provided.

5.151. If the supplementary control room is credited in the safety analysis, supplementary control room air intakes should be separated by distance from the main control room air intakes; their placement at a high level should be considered, particularly if heavy gas clouds have to be considered. However, the effectiveness of separation may depend upon the ability to detect or otherwise become aware of the presence of a toxic or asphyxiant gas in a timely manner. Thus, selection of a specific means of protection should be performed for each particular site.

5.152. For corrosive chemicals, it should be demonstrated that even at the maximum possible rate of corrosion the inspection intervals are such that safety systems could not be impaired to the extent that loss of a safety function could occur before the affected system can be repaired. Protection of systems may be achieved in many ways: by preventing standing contact between corrosive agent and corrodible surface; by providing corrosive gas detectors that activate closure valves; by means of protective coatings; by providing additional wall thickness to allow a certain amount of corrosion; or by reducing intervals between inspections. Specific protection measures, possibly by combining some of these methods, should be determined on a case by case basis. In particular cases, it might even suffice to keep the air temperature or humidity within specified limits, thus slowing down corrosion rates. The adequacy of such an approach should be demonstrated.

ASSESSMENT FOR BEYOND DESIGN CONDITIONS

5.153. Methods in the assessment for beyond design basis releases (BDBEE) should normally be the same as in the design for design basis releases (DBEE). The differences are in the acceptance criteria (see Section 4).

5.8. RADIATION HAZARDS FROM ON-SITE AND COLLOCATED INSTALLATIONS

5.154. The release of radioactive gases and liquids from adjacent operating nuclear units or storage installations, from vehicles containing new or spent fuel and from other on-site and off-site sources constitutes a potential external hazard. The release of radioactive substances may affect the nuclear installation externally and internally, damaging or impairing safety related systems and operator action.

INTERFACE WITH HAZARD ASSESSMENT

5.155. NS-G-3.1 [9] provides information concerning releases of radioactive fluids and recommends procedures for dealing with them. This Safety Guide should be used together with other applicable reference documents for identification of the external radioactive releases to be considered in the design of the installation.

5.156. Beyond design basis releases (BDBEE) should be established by increasing the amount of radioactive substances and/or reducing the distances with respect to the design values (DBEE).

DESIGN AND QUALIFICATION METHODS

5.157. Design against radioactive external hazards should aim at keeping the external and internal exposure of installation personnel within the prescribed regulatory requirements of the Member State. In addition, design should avoid further spreading of radioactive substances that reach the installation.

5.158. In the case of a cloud of radioactive gas, the gas concentration inside the installation should be calculated based on air exchange rates, with assumed meteorological conditions taken into account, thus giving a time dependent concentration and doses. The extension and interaction time of the gas or vapour cloud should be determined on an installation specific basis. Special attention should be paid to releases of radioactive gases to air intakes for the control room and other locations where personnel are present.

5.159. For cases in which a radioactive liquid mixed with water could enter the cooling water intake, the time dependent concentration and radiation dose should be calculated based on the concentration in the cooling water just before the intake. Special attention should be paid to systems that dissipate heat from the installation, since they could contribute to the spread of the released radioactive substances.

MEANS OF PROTECTION

5.160. Given a radioactive external hazard to be considered in the design, two means of protection should be considered by the designer: shielding against radiation exposure, and filtering against contamination with radioactive material.

5.161. Paras 5.147–5.152 discuss means of protection for personnel against asphyxiant and toxic gases. This guidance should also be followed for radioactive gases, as appropriate, in considering control room habitability issues and other related concerns.

5.9. AIRCRAFT CRASH

GENERAL DISCUSSION

5.162. NS-G-3.1 [9] provides recommendations and guidance for estimating the hazard of an aircraft crash on the site and the nuclear installation itself. The result of this analysis, which is based on a screening procedure to identify the potential hazard associated with an aircraft crash, should be expressed in terms of either specific parameters for the aircraft (type, mass, velocity and stiffness) or load-time functions (with associated impact areas).

5.163. SSCs requiring a design for aircraft crash are defined by a safety analysis. Iterations between the designers of the SSCs may occur before the final EE classification determined. All SSCs classified as EE category l and EE category 2 should be designed or evaluated for the aircraft crash event. Malevolent and wartime attacks of aircraft crash are outside the scope of this Safety Guide.

5.164. The postulated aircraft crash should be analysed to determine its effects and the steps necessary to limit the consequences to an acceptable level. In an evaluation for an aircraft crash and other missiles, the following should generally be considered:

- Localized structural damage due to missile impact or impact of extremely stiff parts of the aircraft, for example, the engine and landing gear, including penetration[24], spalling[25], scabbing[26] and perforation ('local effects');
- Global structural damage, including excessive deformations or displacements which prevent the structure from performing its intended safety functions ('global effects');
- Functional failure of SSCs due to induced vibrations in structural members and safety related equipment (‘vibration effects’);
- The effects of fuel initiated fires on SSCs.

[24] Penetration is the state when an impacting missile has formed a notch on the impact face but has not perforated the target.

[25] Spalling is the ejection of target material from an impact face as a result of a missile impact.

[26] Scabbing is the ejection of material from the rear side.

MEANS OF PROTECTION

5.165. When protection of SSCs against an aircraft crash is provided by the design, the different local, global and vibration physical effects of the crash should be borne in mind. Vibration effects should be accommodated by providing redundant and sufficiently separated components, or by vibration isolation measures.

5.166. Directly impacted concrete structures should be reinforced on both sides, with sufficient stirrups.

5.167. The reinforcement should be designed on the basis of the minimum and maximum values (e.g. compression and tension) of the internal forces as calculated and adequately combined with the other prescribed load condition.

5.168. Where local structural failure (including scabbing) could impair a safety function by causing damage to equipment important to safety, the following measures should be taken (also in combination):

- The structural resistance of the shielding structure, or its layout, should be improved by increasing the thickness and/or the reinforcement (or the earth covering in the case of underground distribution systems), by adding missile shields, obstacles or by other appropriate measures;
- Redundant equipment should be located in a different area with an adequate separation distance (physical separation);
- A specific equipment qualification programme should be carried out for the potentially affected items if the equipment is not explicitly qualified for short transient loads but only for steady state vibration in the low frequency range typical for seismic qualification. The evaluation should cover for any equipment all critical failure modes identified in the safety analysis: stability, integrity, functionality.

5.169. When the structural analysis is performed, it is not necessary to combine all design loads with the aircraft crash loading. Generally, it suffices to combine with the aircraft crash loading only those loads expected to be present for a significant duration, i.e., dead and live loads (not including extreme snow or extreme wind) and normal operating loads for equipment.

LOADING AND STRUCTURE

5.170. The characteristics of the primary missile (aircraft), the secondary missiles (engines) and the structure should be defined and explicitly include:

- Type, velocity and impact angles;
- Mass and stiffness;
- Size and location of the impact area;
- Loading capacity and global ductility or local strain limits of the structural systems;
- Consequences of an impact, e.g. fuel effects or debris and secondary missiles

5.171. The location of the impacted area and the impact angle depends on the topology of the surrounding landscape and the neighboring buildings.

5.172. The model of the structure can be differed in the local and the global area. The local area is the impact and the surrounding area, where the structure reacts nonlinear. The nonlinear material laws should be used whereas in the global area linear material behavior can be applied. Applicability of the above mentioned structural modelling should be validated based on the purpose of evaluation described in para. 5.164.

5.173. The material properties for structural steel, steel reinforcement and concrete to be considered in such evaluations should represent the realistic ductility of the materials (defined by test) and should also include strain rate effects.

Load –Time Function

5.174. For impact analysis of stiff or massive structures, an equivalent load-time function should be derived from a defined, deformable missile impacting perpendicular to a rigid target via an analytical approach. After the simulation, a smoothing process should be applied to filter out as far as possible the unavoidable spurious noise from the numerical integration. Attention should be paid not to exclude physical high frequency effects from the load function.

5.175. Load-time functions can be used to consider a DBEE. The engineering design rules should comply with the relevant national or international codes and standards and with proven engineering practice.

Missile-target-interaction

5.176. For impact on flexible structures, the loading might be heavily influenced by the dynamic interaction between missile and target, which can be handled by a coupled analysis (missile-target interaction).

5.177. Whenever a coupled analysis of an aircraft crash is performed, the aircraft type with mass, stiffness, velocity and impact angle as a deformable missile should be modelled. Stiff components, such as engines and landing gears, should be included in the model with their stiffness. The impact is defined by the initial velocity of the missile.

5.178. The flexible target should be modelled in the local area with volume elements for the concrete with sufficient number of elements through the thickness. The nonlinear material behavior of the concrete with its different values in tension and compression, strain rates and failure should be defined. As far as possible the material parameters should be validated using existing experiments.

5.179. In the local area the reinforcing steel (bending and shear) should be modelled with beam elements, connected to the concrete.

5.180. The detailed model in the local area should handle the following effects:

- Failure modes from spalling to perforation of the concrete;
- Plasticity and damage of the steel.

5.181. Outside the local area (equal to global area in para. 5.173) the model of the structure can be simplified in type of elements, detailing of elements and material laws.

5.182. Coupled analysis should be performed for BDBEE by means of a best estimate approach.

5.183. The type of aircraft, mass and velocity can be defined by the regulatory body.

5.184. An alternative approach suitable for assessing the effects of secondary missiles and debris relies on the application of empirical and semi-empirical analytical formulae mainly derived for rigid missiles. The ranges of shape, mass, stiffness and velocity for which they were developed might not usually coincide with those of interest in a typical problem of an aircraft impact on a nuclear installation. Therefore, an engineering judgement of the applicability of this type of approach should be extensively applied.

Miscellaneous aspects

5.185. The soil should be represented by a damped spring mass system. For normal foundations and site conditions, it is sufficient to consider the average dynamic soil conditions of the site, because the variation in soil properties is expected usually to have negligible effects on such analysis.

5.186. The masses of the structural members as well as the dead load of the plant equipment should be considered in the numerical model. Fluid stored in tanks or pools can be represented as rigidly connected masses. Actual live loads should be considered rather than the generally assumed design live loading conditions.

5.187. As some energy is expanded in crushing the impact area and its immediate surrounding, damping in the global area should be chosen lower than in other global dynamic load cases.

5.188. The containment should withstand the impact (without perforation) and one train of systems and components should function after the impact of a design basis aircraft with appropriate fuel load for a long-distance flight.

5.189. In all cases, sensitivity studies should be performed to determine the range of consequences and the most sensitive parameters. In addition, computer codes for non-linear analysis should be verified and validated for analysis of the specific problems identified herein.

VIBRATION EFFECTS

5.190. In-structure response spectra should be calculated for all the main structural elements of the buildings that house safety related equipment.

5.191. For the calculation of the building responses, appropriate damping modelling should be used, with care taken to avoid unreasonable values in the high frequency range.

5.192. The analysis time should be long enough, that dominating vibrations of the structure after the impact are included.

5.193. The unavoidable spurious noise in high frequencies from the numerical analysis is content of the time histories which describe the induced vibrations. Therefore, after the simulation this noise should be filtered out as far as possible before using the induced vibration to design the components.

5.194. The use of a high frequency cut-off in the resulting in-structure response spectra is used in some States, as passive mechanical structures can sustain normally high frequencies without malfunction (damage). This approach is generally used where specific structural layouts are well defined and consider high structural damping at such high frequencies and the presence of structural discontinuities. Such use is only allowed when the calculated displacement is lower than a defined acceptability threshold and the motion is propagated over a distance in the structure.

FUEL EFFECTS

5.195. The outer wall of the structure should be designed to resist the aircraft crash. Neither the aircraft nor parts of it should perforate the outer wall. The consequences that may result from the release of fuel carried by the crashing aircraft should be estimated based on engineering experience. The following aspects should be considered in this estimation:

(a) The fire load should be directly related to the amount of fuel carried by the reference aircraft at the target (corresponding to the assumed scenario of refuelling of aircraft for the route from the starting airport to the destination, fuel consumption from take-off and cruising) and the potential involvement of other flammable material inside the aircraft (hand baggage, luggage, payload, plastics sheeting, seats) and outside present at the site;
(b) Assessment of external fireballs;
(c) Assessment of pool fire;
(d) Entry of fuel into buildings important to safety through normal openings or as a vapour or aerosol through air intake ducts, leading to subsequent fires;
(e) Entry of combustion products into distribution systems, thereby affecting personnel or causing plant malfunctions such as electrical faults or failures in emergency diesel generators.

ASSESSMENT FOR BEYOND DESIGN BASIS AIRCRAFT CRASH

5.196. If for any reason beyond design basis aircraft crash is considered involving fully fueled commercial airplanes, acceptance criteria should be chosen such that as a minimum the safety related items of the nuclear installation that are involved in the fourth level of defence in depth remain functional.

5.10. ELECTROMAGNETIC INTERFERENCE

5.197. Hazards related to electromagnetics interface and radio-frequency interference (EMI/RFI) are defined in paras 8.13–8.15 of NS-G-3.1 [9] To meet these recommendations, the protection of the safety related SSCs of the nuclear installations should be ensured. This protection should be achieved through design and when this is impracticable using administrative measures such as the establishment of exclusion areas.

5.198. The results of the hazard analysis should be well understood, and a clear distinction should be made for sources of EMI/RFI that are offsite and those which originate within the installation boundaries. Both the design approaches and administrative controls may be different depending on the location of the source.

5.199. The evolution of instrumentation and control (I&C) in nuclear installations to include more digital equipment tends to increase its vulnerability to EMI/RFI. Moreover, the development of potential sources of EMI/RFI is very rapid. Therefore, the EMI/RFI protection provided to the nuclear installation SSCs should be reviewed with an increased frequency than compared to other types of hazards.

5.200. If potential sources of electromagnetic pulses (EMPs) have been identified as offsite hazards, the pathways followed by these pulses (e.g. through radiation or conduction) should be well identified and protection should be provided accordingly.

5.201. If the EMP sources are of malevolent origin, close cooperation with nuclear security specialists should be made to respond to EMPs of any origin with a single comprehensive design.

5.202. In designing shielding as EMI/RFI protection, appropriate consideration should be given to materials characteristics, surface finish, corrosion protection, galvanic compatibility and environmental compliance.

5.203. Within the nuclear installation, sources may be stationary or mobile. For all these sources, tests should be performed to verify the adequacy of the design measures. SSCs that are exposed to EMI/RFI should be qualified by testing.

5.204. Where protection through design is not practicable, administrative controls such as exclusion areas should be established, and procedures should be developed for enforcing these measures.

5.11. BIOLOGICAL PHENOMENA

5.205. Biological phenomena mainly affect the availability of cooling water from the UHS and the service water system as consequence of excessive growth of algae, mussels or clams, or clogging by exceptional quantities of fish or jellyfish. Very often malfunctions have also been recorded in ventilation systems because of clogging by leaves or insects in the filters. In some cases, attacking of I&C cables by rats and by bacteria have been recorded. Corrosion effects and accelerated ageing of steel structures exposed to the marine environment can be induced by sulphate reducing bacteria. IAEA Safety Standard Series No. NS-G-1.9, Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants [18] provides guidance on how to deal with such hazards in the design of specific safety related systems.

5.206. The scenarios described in para. 5.205 have usually been found to be combined with flooding, which can cause the sudden removal of marine growth (deposited in different areas) and clogging into the water intake, and strong winds which can cause the clogging of air intakes by leaves or insects in unusual seasonal conditions.

DESIGN METHODS AND MEANS OF PROTECTION

5.207. Analysis of the environmental conditions should be the starting point for the evaluation of such hazards. An inspection regime should be established which takes due account of the need for passive or active control measures and of the rate of growth of the biological matter.

5.208. Specific design provisions should be set up to prevent the clogging of air and water intakes. Screens or redundant paths for clean cooling water for safety related heat exchangers should be provided to protect against failures of intake.

5.209. Measures should also be taken to exclude vegetation and other organisms from entering cooling systems. Major blockages may occur as the result of rare accumulations of vegetation or seaweed loosened by a storm, shoals of fish which can rapidly block the screening systems, or flotsam of a biological or manufactured type. The intake structure should be designed to inhibit marine organisms and plant life from approaching close enough to be caught in the suction flow and trapped against the intake screens. Alternative intakes may be considered.

5.210. Fixed screens may be provided on the intake channels or at the pump house to prevent the ingress of large fish or clumps of seaweed. The outer screens should be designed with sufficient strength to prevent large debris, mammals, fish and alligators or other reptiles from entering the cooling water system. In addition, a second screen using such measures as rotating drum screens should be considered to provide further cleaning of the intake water. A third stage of filtration using fine strainers is also likely to be needed depending on the service water characteristics and heat exchanger design.

5.211. Despite these precautions, a total blockage may still be possible. If the type of event postulated extends over a considerable surface on the site or shoreline, even alternative intakes might not suffice to prevent the blockage. For such cases, a diverse UHS or water intake should be provided.

5.212. Cooling water used in condensers and in heat transport systems directly associated with the UHS should be adequately treated in order to inhibit the growth of organisms within cooling circuits. Further design features should be provided to ease the cleaning of air and water intakes.

5.213. There should be provision for frequent biological monitoring of the UHS to give early warning of changes which might significantly affect its performance. For example, the introduction of new strains of seaweed with different growth habits or greater tolerance to cooling water conditions can affect the availability of water.

5.214. Dedicated operating and maintenance procedures should be developed for the proper monitoring of the phenomena and the prevention of induced accidents. Active control measures may involve treatment using biocides or the use of sacrificial systems.

5.12. COLLISIONS OF FLOATING BODIES WITH WATER INTAKES AND UHS COMPONENTS

5.215. The UHS and the water intake for the service water systems that are important to safety are exposed to the same design basis EEs identified for the safety related buildings at the site, but their design in relation to EEs may present some peculiarities owing to the fact that some components may be beyond the site boundary and they can be spread over a wide area.

5.216. Water intakes and UHS structures can be damaged by ship collision, ice or floating debris. Aside from the actual collision event, associated phenomena should also be considered, such as oil spills or releases of corrosive fluids, which could affect the availability or quality of cooling water.

5.217. The collision of floating bodies with water intakes and UHS structures either is the result of specific scenarios (e.g. a ship collision) or is associated with more complex external event scenarios (e.g. ice and logs during a flood) as described in Refs [7, 9]. Loads from colliding ships and/or impact of debris ice should be combined with other loads depending on the originating scenario (mainly flooding) and the dependencies between these events.

INTERFACE WITH HAZARD ASSESSMENT

5.218. NS-G-3.1 [9] provides guidance on ship collision hazard assessment and defines the important parameters that should be considered in design basis, in case the hazard is relevant for a site. When direct impact cannot be ruled out by the implementation of preventive or protective measures, vessel impact design basis should be established based on the present and expected evolution of traffic in the waterway. The ship collision design basis (DBEE) is normally specified as a size of a vessel and an impact velocity.

5.219. Beyond design basis releases (BDBEE) should be established by increasing the size of the floating body and/or the impact velocity with respect to the design values (DBEE). The approach should be based on the potential maximum size or weight of floating bodies during the installation life, the bathymetry around the plant and the physical limits to navigation conditions around the site.

LOADING

5.220. For design purposes, head-on bow collisions should be considered. Forces from sideways collisions are assumed to be enveloped by bow collision forces. Global collision loads should be in the direction of the vessel travel. The impact force is applied at the water level.

5.221. In addition, for sites in which a safety related intake of water from navigable water bodies is designed, the effects of shipping accidents on the capability to provide the UHS safety function should be considered [7]. Of primary concern is the potential for blockage of the intakes of the heat transport system directly associated with the UHS, which might be caused by sinking or grounding of ships or barges, and the resulting obstruction of intake structure bays, canals or pipes that provide a conduit for water to the intake.

DESIGN AND QUALIFICATION METHODS

5.222. The design of water intakes against ship collision should be capable of providing an adequate level of performance under various environmental conditions and for all the related potential consequences, such as oil spills or releases of corrosive fluids.

5.223. For debris and ice, the dynamic action derived from the analysis of potential events should be applied to the structures that should guarantee integrity.

5.224. For coastal sites, adequate protection measures should be designed in accordance with the codes and standards developed for the traditional mooring and ship protecting structures.

MEANS OF PROTECTION

Prevention measures

5.225. Prevention measures against ship collision should be established in close cooperation with the navigation authorities. Prevention is achieved by providing assistance to navigation through the installation of navigational aids, the introduction of navigation regulations or the implementation of vessel traffic management systems. The collision of large vessels in normal cruising can usually be ruled out by the implementation of this kind of administrative measures.

5.226. If possible, the loss of functions important to safety associated with the water intakes should be prevented by layouts which give due consideration to separation by distance, diversity or redundancy.

Protection measures

5.227. Structures exposed to potential impacts should be designed to withstand the impact loads or, alternatively, a fender or protection system should be deployed to redirect the impact or to reduce the impact loads to non-destructive levels.

5.228. It should be noted that, whenever the resistance of the structure or the protection system is higher than the vessel crushing force, the vessel will crush, and the impact energy will be primarily dissipated by deformation of the vessel. This could result in spillage of fuel-oil or other chemicals. Therefore, the design of any protection system should consider not only the protection of the structure, but also the preservation, to the maximum extent possible, of the vessel to avoid spillage or blockage of the water intake.

5.229. Several types of protective structures are commonly used for structures located in ports or waterways. Many of them can be adapted to protection of water intakes and UHS components (e.g. fender systems, pile supported systems, dolphin protection or floating protection systems). Similar systems should also be developed to prevent direct debris impact or build-up of ice.

5.230. Where a potential direct collision with the intake structure is of concern, measures should be taken to maintain the supply of cooling water and UHS safety functions. Particularly, not only is structural integrity a concern but also the effects of the collision on components of the heat transport systems directly associated with the UHS should be considered (e.g. induced vibration during impact).

Mitigation measures

5.231. In the case of potential spillage of liquids which readily mix with the intake water and which could result in damage to the heat transport system or could seriously degrade the heat transfer capability, adequate provisions should be taken. For oil spills, protection should be provided by the proper submergence of pump intake parts. However, in cases involving shallow submergence, special measures such as booms or skimmers which keep the oil at a safe distance from the pump intake parts should be implemented. Such measures may also be necessary if the potential for ignition of the oil or other fluid is of concern.

5.232. If blockage of an intake possible to the extent that the necessary minimum heat transport system flow cannot be ensured, then either redundant means of access to the UHS or diverse means of fulfilling the design objective for the UHS should be provided. In the event of a ship collision associated phenomena should be considered, such as oil spills or releases of corrosive fluids which could affect the availability or quality of cooling water.

5.233. In the case of a significant hazard for ice, the static and dynamic action on the intakes derived from debris and ice should be considered. Alternatively, a different method of providing cooling water to the plant should be provided [27], for example from a different source or by a closed loop air cooled system.

ASSESSMENT FOR BEYOND DESIGN CONDITIONS

5.234. Methods in the assessment for beyond design basis collision (BDBEE) should normally be the same as in the design for design basis releases (DBEE). The differences are in the acceptance criteria and the material properties used in the assessment (see Section 4).

5.13. OTHER EXTERNAL HAZARDS

5.235. Geotechnical hazards, not associated with seismic loads should be considered in the design. In general, hazards such as subsidence or cavity collapse involve both soil remediation

[27] For example, pumping (warm) cooling water from a discharge basin when ice clogs the intake screens is the practice in some Members States.

and foundation design and therefore close cooperation with the geotechnical hazard evaluation team should be maintained (See also IAEA Safety Standard Series No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants [19]).

5.236. Combination of hazards may be used as BDBEEs for those events for which a BDBEE has not been considered above.

5.14. COMBINATION OF HAZARDS

5.237. In general, external hazards should not be combined with other extreme loads unless the following conditions are present:

- The external event triggers the occurrence of another external event, such as a tsunami is triggered by an earthquake or a submarine landslide. In this case, the effects of both EEs on the nuclear installation should be considered with due regard to the time difference between the events felt at the site;
- The external event comprises several potential hazards which may all occur at the site. For example, a large airplane crash at the site has the potential to cause impact, vibration, explosion and fire at the site, all of which should be considered;
- The external event causes a change in the plant state (from normal operation to accident conditions including DECs). This possibility should be evaluated and considered in the safety evaluation of the nuclear installation.

6. SAFETY DESIGN PROVISIONS FOR NUCLEAR INSTALLATIONS OTHER THAN NUCLEAR POWER PLANTS

6.1. This Safety Guide addresses the range of nuclear installations[28] as defined in Ref. [5]. NPPs are the focus of previous sections; however, the methodologies recommended for NPPs are applicable to other nuclear installations by means of a graded approach.

6.2. The bases for the design basis requirements for EEs are the protection of people and the environment against radiation risks and the safety of facilities and activities that give rise to radiation risks.[29]

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[28] The term ‘nuclear installation’ includes: nuclear power plants; research reactors (including subcritical and critical assemblies) and any adjoining radioisotope production facilities; spent fuel storage facilities; facilities for the enrichment of uranium; nuclear fuel fabrication facilities; conversion facilities; facilities for the reprocessing of spent fuel; facilities for the predisposal management of radioactive waste arising from nuclear fuel cycle facilities; and nuclear fuel cycle related research and development facilities.

[29] The integrity of an installation’s mission is recognized as important, but it is not explicitly an element of the performance criteria to be implemented for the nuclear installation.

6.3. A graded approach means that designs for EEs and evaluations for BDBEEs can be customized for nuclear installations of different types in accordance with the severity of the potential radiological consequences of their failure. A graded approach is used to provide higher levels of protection against events that could result in higher risk. Member States should decide what level of risk is acceptable and what level of protection against the EE should be provided.

6.4. The recommended approach to grading is to start with attributes relating to NPPs and, if possible, to grade down to installations with which lesser radiological consequences are associated.[30] If no grading is justified, the recommendations for NPPs are applicable, as far as practicable, to other types of nuclear installations.

6.5. The likelihood that an EE would give rise to radiological consequences will depend on the characteristics of the nuclear installation (e.g. its use, design, construction, operation and layout) and on the event, itself. Such characteristics include the following factors:

(a) The amount, type and status of radioactive inventory (e.g. solid, fluid, processed or only stored);
(b) The intrinsic hazard associated with the physical processes (e.g. criticality) and chemical processes that take place at the installation;
(c) The thermal power of the nuclear installation, if applicable;
(d) The configuration of the installation for activities of different kinds;
(e) The concentration of radioactive sources within the installation (e.g. in research reactors, most of the radioactive inventory will be in the reactor core and fuel storage pool, while in processing and storage plants it may be distributed throughout the plant);
(f) The changing nature of the configuration and layout of installations designed for experiments;
(g) The need for active safety systems and/or operator actions to cope with mitigation of postulated accidents; characteristics of engineered safety features for preventing accidents and for mitigating the consequences of accidents;
(h) The characteristics of the process or of the engineering features that might show a cliff edge effect in the event of an accident;
(i) The potential for on-site and off-site contamination.

6.6. Depending on the criteria of the regulatory body, some or all the above factors should be considered. For example, fuel damage, radioactive releases or doses may be the conditions or metrics of interest.

6.7. Decisions related to the BDBEE for non-NPP installations should be based, if relevant, on the grading considerations following Requirement 22 in SSR-3 [2] and Requirement 21 in SSR-4 [3].

6.8. Prior to categorizing an installation, a conservative screening process should be applied. The assumption that the complete radioactive inventory of the installation is released in an EE

[30] For sites at which nuclear installations of different types are collocated, particular consideration should be given to using a graded approach.

initiated accident is a first level screen. If the result of such a release is that no unacceptable consequences are possible for on-site workers, the public, or the environment, and no other specific requirements for such an installation are imposed by regulatory bodies or the owner, the installation may be screened out from the EE. Unacceptable radiological consequences are doses to workers or the public above acceptable limits established by the Member State.

6.9. In such a case, the design, construction, operation, maintenance, and future reviews are subject to the State's codes and standards for commercial and/or industrial facilities.

6.10. If the results of the conservative screening process show that the consequences of the potential release of the complete radioactive inventory are 'significant', a next level screening may be implemented, i.e., screening by magnitude and distance (SDV) and screening based on an annual probability of occurrence (SPL) (see para. 3.3). If the SDV or SPL screening applies (i.e. if the results demonstrate insignificant consequences), the results should be documented, and the EE may be eliminated from consideration.

6.11. The grading process should be based on the following information:

- The safety analysis report for the installation should be the primary source of information;
- The results of a probabilistic safety assessment, if one has been performed;
- The characteristics specified in para. 6.5.

6.12. For an existing installation, the grading may have been performed in the design stage or later, e.g. at a periodic safety review. If so, the assumptions on which this grading was based, and the resulting categorization should be reviewed and verified. The results may range from no radiological consequences (associated with conventional installations) to high radiological consequences, i.e. for consequences associated with NPPs.

6.13. As a result of this grading process, three or more categories of installation may be defined depending on State practice:

(a) The least radiologically hazardous installations are similar to conventional facilities (essential facilities, such as hospitals); other non-radiologically hazardous facilities, such as petrochemical plants, are outside the scope of this Safety Guide;
(b) The highest grade of hazardous installation would be installations for which the risks involved to the environment and population are comparable to the risks from NPPs;
(c) There is often one or more intermediate category of hazardous installation specified as being between those defined as equivalent to conventional facilities (essential facilities or hazardous facilities) and the category for NPPs.

6.14. The evaluation of EE hazards, design, and evaluation should be performed using the following guidance:

(a) For the least hazardous installations, the EE hazards may be taken from national building codes and maps; design criteria may be based on codes and standards of the State for important facilities; BDBEEs may be considered in a simplistic manner.

(b) For installations in the highest hazard category, EE hazards, design procedures, and evaluation procedures should be implemented as described in previous sections of this Safety Guide for NPPs, including BDBEEs and cliff edge effects.

(c) For installations categorized in the intermediate hazard category, the following cases may be applicable:

- If the evaluation of EE hazards is performed using methodologies similar to those described in this Safety Guide for NPPs, two approaches may be implemented to determine a lower loading condition than for NPPs: (i) if the EE hazard is defined probabilistically, a higher annual frequency of exceedance may be selected for design of the installation and evaluation of the installation for BDBEEs, with the approval of the regulatory body; (ii) if the EE hazard is defined deterministically, a loading condition less than that for the NPP may be selected for design based on the precedent set in a State for other non-radiologically hazardous facilities, with the approval of the regulatory body. similarly, BDBEE loading conditions may be selected for assessing margin.
- If the database and the methods recommended in this Safety Guide are found to be excessively complex and time and effort consuming for the nuclear installation in question, simplified methods for the evaluation of EE hazards, based on a more restricted data set, can be used. In such cases, the input parameters finally adopted for designing these installations should be commensurate with the reduced database and the simplification of the methods, with account taken of the fact that both of these factors may tend to increase uncertainties.

7. APPLICATION OF MANAGEMENT SYSYTEM

7.1. The management system should ensure the quality and the control of the activities performed at each stage of the design.

7.2. As part of the management system, the design process or processes for the development of the concept, detailed plans, supporting calculations and specifications for a nuclear installation and its parts, should be established and conducted following the recommendations and guidance provided in IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [20].

7.3. Design inputs, processes, requirements, outputs, changes and records should be established and controlled. The design outputs include specifications, drawings, procedures and instructions, including any information necessary to implement or install the designed SSCs or protective measures.

7.4. Design inputs, processes, outputs and changes should be verified. Individuals or groups performing design verification should be qualified to perform the original design. Those carrying out verification should not have participated in the development of the original design (but they may be from the same organization). The extent of verification should be based on the complexity, the associated hazards and the uniqueness of the design. Some typical design verification methods include design review, carrying out calculations by an alternative method and qualification testing.

Previously proven designs should not be subject to verification unless they are intended for different applications or the performance criteria are different. Design records, including the final design, calculations, analyses and computer programs, and sources of design input that support design output, are normally used as supporting evidence that the design has been properly accomplished [20].

7.5. The design process should include the following activities; recommendations and guidance on these activities are provided in paras 5.87–5.140 of GS-G-3.5 [20]:

(a) Design initiation, specification of scope and planning;
(b) Specification of design requirements;
(c) Selection of the principal designer;
(d) Work control and planning of design activities;
(e) Specification and control of design inputs;
(f) Review of design concepts and selection;
(g) Selection of design tools and computer software;
(h) Conducting conceptual analysis;
(i) Conducting detailed design and production of design documentation;
(j) Conducting detailed safety analyses;
(k) Defining any limiting conditions for safe operation (sometimes referred to as the safe operating envelope);
(l) Carrying out design verification and validation;
(m) Configuration management;
(n) Management of the design and control of design changes.

7.6. Computer programs used in design should be validated through testing or simulation prior to use, if they have not already been proven through previous use [20].

7.7. Interfaces among all organizations involved in the design should be identified, coordinated and controlled. Control of interfaces includes the assignment of responsibilities among, and the establishment of procedures for use by, participating internal and external organizations [20].

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standard Series No. SSR-2/1, (Rev. 1), IAEA, Vienna (2016).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Research Reactors, IAEA Safety Standard Series No. SSR-3, IAEA, Vienna (2016).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standard Series No. SSR-4, IAEA, Vienna (2017).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standard Series No. SSR-1, Vienna (2017).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, IAEA, Vienna (2018).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standard Series No. SSG-9, Vienna (2010). (a revision of this publication is in preparation.)

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, WORLD METEOROLOGICAL ORGANIZATION, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA, Vienna (2011).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Volcanic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-21, IAEA, Vienna (2012).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, External Human Induced Events in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.1, IAEA, Vienna (2002).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Fire and Explosions in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.7, IAEA, Vienna (2004). (a revision of this publication is in preparation.)

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Hazards other than Fire and Explosions in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.11, IAEA, Vienna (2004). (a revision of this publication is in preparation.)

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Design and Qualification for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.6, IAEA, Vienna (2003). (a revision of this publication is in preparation.)

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Periodic Safety Review for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-25, IAEA, Vienna (2013).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of Seismic Safety for Existing Nuclear Installations, IAEA Safety Standards Series No. NS-G-2.13, IAEA, Vienna (2009).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Engineering Safety Aspects of the Protection of Nuclear Power Plants against Sabotage, IAEA Nuclear Security Series No. 4, IAEA, Vienna (2007).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), IAEA, Vienna (2016).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Deterministic Safety Analysis for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-2, IAEA, Vienna (2009). (a revision of this publication is in preparation.)

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.9, IAEA, Vienna (2004). (a revision of this publication is in preparation.)

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.6, IAEA, Vienna (2004).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Nuclear Installations, IAEA Safety Standards Series No. GS-G-3.5, IAEA, Vienna (2009).

LIST OF ABBREVIATIONS

BDBEE	Beyond Design Basis External Event
DEC	Design Extension Condition
DBEE	Design Basis External Event
EE	External Event
EE-PSA	External Event Probabilistic Safety Assessment
NPP	Nuclear Power Plant
SDV	Screening Distance Value
SPL	Screening Probability Level
SSC	Structure, System and Component
UHS	Ultimate Heat Sink

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