

IAEA Safety Standards

for protecting people and the environment

Design of Nuclear Installations Against External Events Excluding Earthquakes

Specific Safety Guide

No. SSG-68



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International Atomic Energy Agency



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IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

<https://www.iaea.org/resources/safety-standards>

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

DESIGN OF
NUCLEAR INSTALLATIONS
AGAINST EXTERNAL EVENTS
EXCLUDING EARTHQUAKES



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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. SSG-68

DESIGN OF
NUCLEAR INSTALLATIONS
AGAINST EXTERNAL EVENTS
EXCLUDING EARTHQUAKES
SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish...standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures¹ have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

¹ See also publications issued in the IAEA Nuclear Security Series.

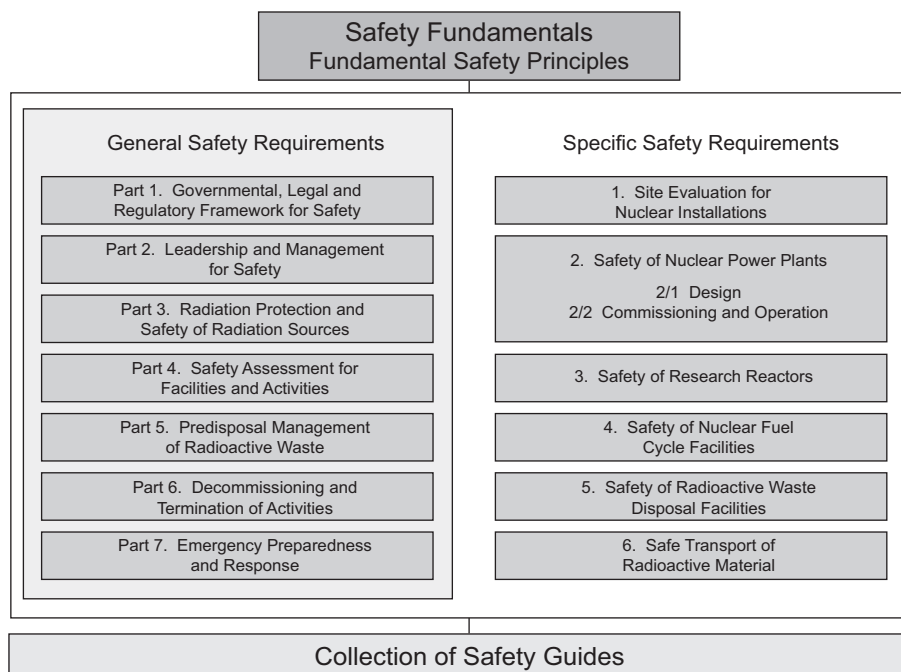


FIG. 1. The long term structure of the IAEA Safety Standards Series.

is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be

used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

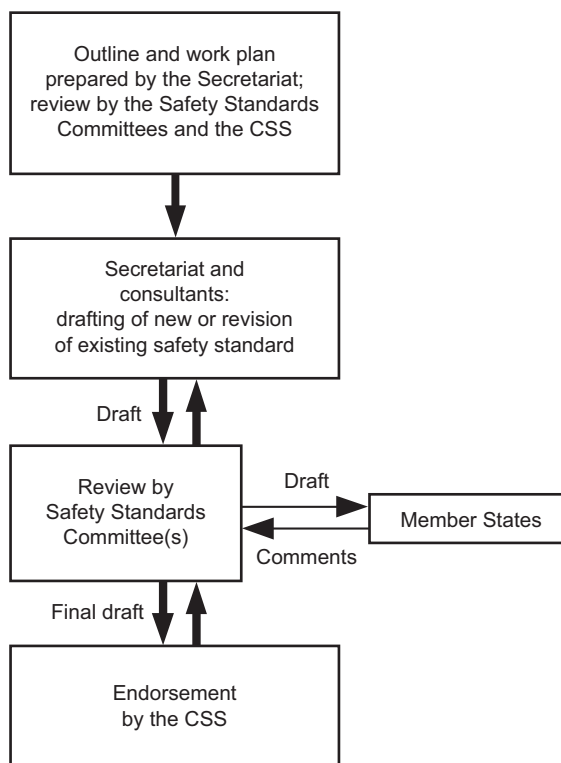


FIG. 2. The process for developing a new safety standard or revising an existing standard.

It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see <https://www.iaea.org/resources/safety-standards/safety-glossary>). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

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1. INTRODUCTION

BACKGROUND

1.1. Requirements for the design of nuclear installations are established in IAEA Safety Standards Series Nos SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1]; SSR-3, Safety of Research Reactors [2]; and SSR-4, Safety of Nuclear Fuel Cycle Facilities [3].

1.2. IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [4], establishes requirements for the external hazards that need to be considered in the evaluation of sites for nuclear installations.

1.3. This Safety Guide provides specific recommendations on the design of nuclear installations to cope with the effects of external events¹, excluding earthquakes.

1.4. This Safety Guide incorporates progress in the design of nuclear installations and in regulatory practice in States, taking into account lessons identified from extreme external events, feedback from safety review missions and the results of recent research on the effects of all external events excluding earthquakes. This Safety Guide provides new or updated recommendations on the following topics:

- (a) General concepts and application of safety criteria relating to the following:
 - (i) The design of structures, systems and components (SSCs) for protection against external events;
 - (ii) Load combinations;
 - (iii) The establishment of acceptance criteria.

¹ An external event is an event that is unconnected with the operation of a facility or the conduct of an activity that could have an effect on the safety of the facility or activity [5]. Such events normally originate outside the site, and their effects on the nuclear installation need to be considered. Events originating on the site but outside safety related buildings are treated the same as off-site external events. External events could be of natural or human induced origin and are identified and selected for design purposes during the site evaluation process.

- (b) Safety analysis for design basis external events² and beyond design basis external events³.
- (c) The design basis for each external event.
- (d) Categorization of SSCs.
- (e) Design and qualification methods and means of protection.
- (f) Application of the management system.

1.5. Recommendations on site evaluation, focusing on the assessment of hazards, are provided in IAEA Safety Standards Series Nos SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [6]; SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [7]; SSG-21, Volcanic Hazards in Site Evaluation for Nuclear Installations [8]; and NS-G-3.1, External Human Induced Events in Site Evaluation for Nuclear Power Plants [9].

1.6. Other Safety Guides provide recommendations on the design of nuclear installations for protection against the effects of hazards other than those addressed here and, as such, are complementary to this Safety Guide, particularly for the consideration of combinations of hazards and effects. These include IAEA Safety Standards Series Nos SSG-64, Protection against Internal Hazards in the Design of Nuclear Power Plants [10], and SSG-67, Seismic Design for Nuclear Installations [11].

1.7. This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-1.5, External Events Excluding Earthquakes in the Design of Nuclear Power Plants⁴.

² A design basis external event is an external event, or a combination of external events, that is considered in the design basis of all or any part of a facility [5]. Design basis external events are independent of the installation layout.

³ The term ‘beyond design basis external event’ is used to indicate a level of external hazard exceeding those hazard levels considered for design, derived from the hazard evaluation for the site. The purpose of identifying beyond design basis external events is to ensure that the design incorporates features to enhance the capability of the installation to withstand such events. In addition, the identification of such events is used in evaluating the margins that exist in the design and in identifying potential cliff edge effects.

⁴ 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).

OBJECTIVE

1.8. The objective of this Safety Guide is to provide recommendations on the design of nuclear installations for protection against the effects of external events excluding earthquakes. In particular, this Safety Guide is intended to provide recommendations on engineering related matters in order to meet the applicable safety requirements established in SSR-2/1 (Rev. 1) [1], SSR-3 [2] and SSR-4 [3] for the protection of nuclear installations against such events.

1.9. This Safety Guide also provides methods and procedures for defining an appropriate design for a nuclear installation on the basis of the site hazard evaluation and the layout of the installation. The aim is to provide guidance for the design of the installation, in particular for the protection of SSCs important to safety against design basis external events to ensure the safety of the installation.

1.10. This Safety Guide also provides recommendations on the selection of beyond design basis external events in order to check and verify margins and avoid cliff edge effects⁵.

1.11. This Safety Guide is intended for use by organizations involved in the design of nuclear installations against external events; in analysis, verification and review; and in the provision of technical support. It is also intended for use by regulatory bodies for the establishment of regulatory guides.

SCOPE

1.12. This Safety Guide is applicable to all types of nuclear installation, as defined in the IAEA Safety Glossary [5]. This includes nuclear power plants; research reactors (including subcritical 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.

⁵ A cliff edge effect is an instance of severely abnormal conditions caused by an abrupt transition from one status of a facility to another following a small deviation in a parameter or a small variation in an input value [5].

1.13. This Safety Guide is applicable to the design of new nuclear installations and the safety evaluation of existing nuclear installations in relation to the following external events:

- (a) Human induced events:
 - (i) Accidental aircraft crashes;
 - (ii) Explosions (i.e. deflagrations and detonations) with or without fire and with or without secondary missiles⁶;
 - (iii) Release of corrosive or hazardous gases or liquids (e.g. asphyxiant, toxic) from off-site or on-site storage or during transport;
 - (iv) Release of radioactive material from off-site sources or from the site;
 - (v) Fire generated off the site or from on-site sources;
 - (vi) Collision of ships or floating debris with safety related structures, such as water intakes or structures associated with the ultimate heat sink;
 - (vii) Collision of vehicles with SSCs;
 - (viii) Electromagnetic interference from off-site or on-site sources;
 - (ix) Floods resulting from the rupture of external pipes;
 - (x) Any combination of the above resulting from a common initiating event, for example an explosion with fire and a release of hazardous gases and smoke.
- (b) Natural events:
 - (i) Floods due to events such as tides; tsunamis; seiches; storm surges; wind generated waves; precipitation causing flooding of nearby rivers and streams; dam forming and dam failures; bores and mechanically induced waves; channel migration; and high groundwater levels;
 - (ii) Extreme meteorological conditions (of temperature, snow, hail, frost, subsurface freezing and drought);
 - (iii) Extreme winds, including straight line winds, winds due to tropical storms (e.g. cyclones, hurricanes, typhoons) and tornadoes;
 - (iv) Dust and sandstorms;
 - (v) Lightning;
 - (vi) Volcanism;
 - (vii) Biological phenomena;

⁶ The term ‘missile’ is used to describe a mass that has kinetic energy and has left its design location. This term is used to describe a moving object in general; military missiles, whether explosive or not, 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.

- (viii) Collision of floating objects (e.g. ice, logs) with safety related structures such as water intakes and components of the ultimate heat sink;
- (ix) Geotechnical hazards (not associated with seismic loads);
- (x) Any combination of the above.

This list might not be exhaustive for every site. Consequently, any other external events that are relevant for the site should be identified and evaluated. The hazards associated with external events may be affected by changes that have occurred since the siting process, as indicated in SSR-1 [4]. Such changes are considered in periodic safety reviews [12]. However, the hazard definition and protection concept also need to be reviewed following significant events that identify shortfalls in current knowledge and understanding, as well as when other significant new information has become available.

1.14. Throughout this publication, the term ‘external events’ always excludes earthquakes, for which recommendations are provided in SSG-67 [11].

1.15. The external human induced events considered in this Safety Guide are of accidental origin. Actions relating to sabotage are outside the scope of this Safety Guide, although some of the safety measures described might also be consistent with the needs of nuclear security. Specific guidance on the protection of nuclear power plants against sabotage is provided in Ref. [13].

1.16. The recommendations in this Safety Guide apply to all types of nuclear installation (see para. 1.12), including reactor types other than water cooled reactors at stationary nuclear power plants. The recommendations provided for nuclear power plants are also applicable to other nuclear installations through the application of a graded approach. Section 6 provides recommendations on the graded approach that should be followed for different types of nuclear installation.

1.17. This Safety Guide is mainly focused on the design stage of a new nuclear installation. However, the recommendations are also applicable in the re-evaluation of existing installations and in the periodic safety review described in IAEA Safety Standards Series No. SSG-25, Periodic Safety Review for Nuclear Power Plants [12].

STRUCTURE

1.18. The general concepts and application of safety criteria to the design of nuclear installations for protection against external events are presented in Section 2, including the relevant safety requirements; SSCs to be protected against external events; and recommendations on design and evaluation for design basis external events and beyond design basis external events and for the determination of adequate margins. Recommendations on the derivation of design parameters from the site evaluation, and on the overall design approach and evaluation of beyond design basis external events, are provided in Section 3. Recommendations on installation layout and the approach to the design of buildings are provided in Section 4. Recommendations on specific external events are provided in Section 5. Section 6 provides recommendations on design provisions for nuclear installations other than nuclear power plants using a graded approach. Section 7 provides recommendations on the application of the management system to the design of nuclear installations for protection against external events.

2. GENERAL CONCEPTS AND APPLICATION OF SAFETY CRITERIA TO THE DESIGN OF NUCLEAR INSTALLATIONS AGAINST EXTERNAL EVENTS

REQUIREMENTS FOR SITE EVALUATION

2.1. In accordance with Requirement 7 of SSR-1 [4], proposed sites for a nuclear installation are required to be evaluated in terms of natural and human induced external events, with emphasis on the frequency of exceedance and severity of the events. Hazards should be evaluated using deterministic and, as far as practicable, probabilistic methods, taking into account best practice. Potential combinations of such events are also required to be considered in the design of the installation (see para. 4.20 of SSR-1 [4]).

DESIGN REQUIREMENTS FOR NUCLEAR INSTALLATIONS

2.2. The requirements relevant to the design of nuclear power plants are established in SSR-2/1 (Rev. 1) [1]. For the design of research reactors and nuclear fuel cycle facilities, relevant requirements are established in SSR-3 [2]

and SSR-4 [3], respectively. All these Safety Requirements publications stress the importance of applying a graded approach. Where no specific safety requirements for design have been established for a particular type of nuclear installation, the requirements established in SSR-2/1 (Rev. 1) [1], SSR-3 [2] and SSR-4 [3] should be applied, as far as practicable, using the graded approach described in Section 6.

External hazards

2.3. With regard to considering external hazards in the design of nuclear power plants, SSR-2/1 (Rev. 1) [1] states (footnotes omitted in paras 5.17 and 5.21):

“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 external events (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.

“5.21A. 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 hazard evaluation for the site.”

Similar provisions for considering external hazards are established in Requirement 19 of SSR-3 [2] for the design of research reactors and in Requirement 16 of SSR-4 [3] for the design of nuclear fuel cycle facilities.

Engineering design rules

2.4. SSR-2/1 (Rev. 1) [1] states:

“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.”

Similar provisions for engineering design rules and proven engineering practices are established in Requirement 13 of SSR-3 [2] for the design of research reactors and in Requirement 12 of SSR-4 [3] for the design of nuclear fuel cycle facilities.

Design extension conditions

2.5. SSR-2/1 (Rev. 1) [1] states:

“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.”

The same provisions for design extension conditions are established in Requirement 22 of SSR-3 [2] for the design of research reactors and in Requirement 21 of SSR-4 [3] for the design of nuclear fuel cycle facilities.

Heat transfer to an ultimate heat sink

2.6. SSR-2/1 (Rev. 1) [1] states that with respect to nuclear power plants:

“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.”

There are no equivalent requirements in SSR-3 [2] or SSR-4 [3] in relation to the design of research reactors or nuclear fuel cycle facilities. Consequently, where the design of other nuclear installations needs to include the capability to transfer heat to an ultimate heat sink, a graded approach should be applied using the requirements established in SSR-2/1 (Rev. 1) [1] as a starting point.

Control room

2.7. SSR-2/1 (Rev. 1) [1] states:

“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.”

Similar provisions for the control room are established in Requirement 53 of SSR-3 [2] for the design of research reactors; however, there are no equivalent requirements in SSR-4 [3] for the design of nuclear fuel cycle facilities.

OTHER ASPECTS OF DESIGN AGAINST EXTERNAL EVENTS

2.8. The hazard evaluation (see para. 2.1) should provide the following information:

- (a) The severity levels of hazards and the annual frequencies of exceedance;
- (b) Descriptions of the hazard evaluation methods and the elements and parameters of importance (including screening methods, results and uncertainties);
- (c) The assumptions made in the hazard evaluation process.

This information should be communicated to the organization responsible for the design of the nuclear installation.

2.9. Two levels of external hazard should be considered in the design and evaluation of the SSCs important to safety in a nuclear installation that are subjected to external events. The first level is the design basis external event, and the second level is the beyond design basis external event. The frequencies of exceedance of design basis external events should be low enough that the design measures applied will ensure a high degree of protection with respect to external hazards.⁷ It should be specified whether the frequencies of exceedance of the design basis external events refer to the mean, the median or a specific percentile.

2.10. The organization responsible for the design of the nuclear installation should define the loading conditions for design basis external events to be used in the design of SSCs and the loading conditions to be used in the evaluation of SSCs for beyond design basis external events. These loading conditions should be determined using the information from the hazard evaluation.

2.11. A design with an adequate margin, as required by para. 5.21 of SSR-2/1 (Rev. 1) [1], is achieved through conservative design approaches, duly taking into account the variability and uncertainties of the different methods, data, assumptions and rules used. The aim is to ensure that SSCs have the capability to perform safely even in situations more severe than those postulated in the design basis, without the occurrence of cliff edge effects. A source of margin is provided in the design of SSCs for a wide range of internal and external extreme loads. The governing loads for some SSCs could be different from, for example, the pressure and other environmental loads due to accident conditions, aircraft crashes, tornadoes, pipe breaks or seismic loads.

2.12. With regard to the design of SSCs, adequate margins are derived from the method used to define the loading conditions and from compliance with stress limits defined by the design codes and manufacturing codes. Nuclear design codes and standards implicitly or explicitly yield the margin achieved in the design process for individual SSCs. The margin for individual SSCs (i.e. the margin that results from the consideration of a variety of load cases) or for the nuclear installation as a whole should be achieved through the chain of steps from specifying the loading parameters to defining and achieving the performance acceptance criteria for the SSCs.

⁷ In many States, a target frequency of exceedance of 10^{-4} per year or less is used for design basis external events for natural hazards.

2.13. For the purpose of this Safety Guide, the term ‘adequate margin’ refers to the following:

- (a) The overall capacity of the nuclear installation to withstand the loading conditions of design basis external events;
- (b) The capacity of individual SSCs to perform their intended function when subjected to the loading conditions of design basis external events;
- (c) The avoidance of any cliff edge effects due to beyond design basis external events.

2.14. A design basis external event and its corresponding loading conditions should be defined conservatively in terms of the associated margins, to take into account any uncertainties.

2.15. Beyond design basis external events can be defined in the following ways:

- (a) By adopting a lower annual frequency of exceedance than that specified for the design basis external event.
- (b) By adopting a higher amplitude in the design basis external event loading conditions for all SSCs important to safety, or for a subset of SSCs ultimately necessary to prevent an early radioactive release or a large radioactive release. One approach is to add a factor of conservatism to the design basis external event loading conditions for such SSCs.

2.16. When considering a beyond design basis external event and following a best estimate approach, values of external event parameters causing cliff edge effects should be established. Adequate margins to these values should be demonstrated.

2.17. An assessment of adequate margins should be performed to determine either of the following:

- (a) The level of the loading conditions at which the applicable safety functions for the installation or the function of an SSC important to safety would be compromised. This assessment process should include the identification of weak links and areas of improvement for engineering design. The margin assessment should also identify the potential for cliff edge effects due to external events and estimate their probability of occurrence.
- (b) The level of the loading conditions at which there is high confidence that the applicable safety functions for the installation would be fulfilled and at which there would be no cliff edge effects as a result of slightly greater loading conditions.

These two approaches represent the probabilistic approach and the deterministic approach, respectively. The probabilistic approach should provide the best estimate of the level of loading conditions at which the applicable safety functions for the installation would continue to be fulfilled. The deterministic approach should provide conservative values at which there is high confidence that the applicable safety functions for the installation would be fulfilled.

2.18. 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 using full probabilistic models of the loading conditions, the response of the installation and the capacity of SSCs important to safety. The best estimate value should be convolved over the range of values or derived as a point estimate using a simple best estimate model in which the loading condition is defined as the mean or median value and all installation parameters are assigned their best estimate values.

2.19. In the deterministic approach, a metric should be defined for the margin assessment. One such approach uses the ‘high confidence of low probability of failure’ capacity. This approach is commonly used in seismic margin assessments, and further recommendations are provided in SSG-67 [11] and IAEA Safety Standards Series No. NS-G-2.13, Evaluation of Seismic Safety for Existing Nuclear Installations [14].

2.20. The margins to be defined for various external hazards depend on the attributes of these hazards. Some attributes potentially increase the severity or the consequences of external events, while others potentially mitigate the effects of external events. The following factors should be considered in defining adequate margins:

- (a) Factors that potentially make the effects of external events on a nuclear installation (especially a nuclear power plant) more severe and more uncertain:
 - (i) The potential for causing cliff edge effects.
 - (ii) Uncertainties in the hazard evaluation (e.g. database issues, such as completeness and constraints for maximum values).
 - (iii) Limited experience of specific external events or in relation to specific nuclear installations (i.e. maturity of subject matter).
 - (iv) The potential for combination with other external events and for interdependencies (e.g. high winds and flood; earthquake ground motion, fault displacement and tsunami).

- (v) The potential for an external event to cause an internal event (e.g. an earthquake causing an internal fire or flood).
- (vi) The extent of common cause failure, such as the following:
 - Simultaneous effects on all SSCs in one installation, on multiple units in a nuclear power plant or on multiple nuclear power plant sites;
 - Potential compromise of redundancy of systems or of defence in depth;
 - A simultaneous challenge to on-site and off-site emergency response measures.
- (b) Factors that potentially mitigate the effects of external events on a nuclear installation:
 - (i) The potential for advanced warning, such as the following:
 - Warning time in hours for extreme weather conditions or external flooding (e.g. due to hurricane or cyclone, river flood, or tsunami from a distant source) and for dust in air intakes (e.g. due to volcano eruption or sandstorm);
 - Warning time in minutes or less for extreme wind (e.g. tornado).
 - (ii) Having sufficient time to shut down the reactor (orderly or scram), noting that the shutdown state will need to be evaluated.
 - (iii) The extent of common cause failure, for example a limited spatial effect (footprint) due to tornado or aircraft crash.

2.21. In the evaluation of the safety of the nuclear installation in relation to beyond design basis external events, acceptance criteria applicable to the treatment of design extension conditions should be applied.

STRUCTURES, SYSTEMS AND COMPONENTS TO BE PROTECTED AGAINST EXTERNAL EVENTS

2.22. In the design and evaluation process for each individual external event, all SSCs important to safety that are affected by or exposed to the external event under consideration should be identified, including those SSCs whose failure could jeopardize SSCs important to safety. The list of the identified SSCs should include all equipment and any barriers or protective structures built to specifically address the external event.

2.23. The categorization of SSCs in relation to external events should follow the recommendations on seismic categorization provided in paras 3.31–3.40 of SSG-67 [11]. SSCs that are comparable to SSCs in seismic category 1 should

be categorized as external event category 1. SSCs in external event category 1 should be designed to withstand the respective design basis external event, and an adequate margin should be provided to avoid cliff edge effects.

2.24. External event category 2 should be established for SSCs whose failure could jeopardize SSCs in external event category 1. Similar to seismic category 2, it should be demonstrated that SSCs in external event category 2 that have the potential to interact with SSCs in external event category 1 are effectively prevented from impairing those external event category 1 SSCs. SSCs in external event category 2 should be designed for the design basis external event, or it should be demonstrated that their failure will not impact the safety function of the external event category 1 SSCs.

2.25. External event category 3 should include all items that are not in external event categories 1 or 2. The items in external event category 3 should, at a minimum, be designed in accordance with the national approach to the external event design of high risk conventional (i.e. non-nuclear) installations.

DESIGN AND EVALUATION FOR DESIGN BASIS EXTERNAL EVENTS AND BEYOND DESIGN BASIS EXTERNAL EVENTS

2.26. The design of a nuclear installation for an external event should take into account all credible consequential effects of that event. External events can challenge the safety of a nuclear installation by different means, such as the following:

- (a) Deterioration of site protection features (e.g. failure of human-made earthen structures, shielding walls or dykes);
- (b) Deterioration of structural capabilities (e.g. leaktightness; structural integrity; support to equipment, components or distribution systems);
- (c) Impairment of equipment operation;
- (d) Impairment of redundancy of function due to common cause failure;
- (e) Impairment of the capability of operating personnel;
- (f) Unavailability of a heat sink;
- (g) Unavailability of off-site power sources or off-site services and resources.

2.27. Having selected the external events to be considered for a particular site in accordance with the requirements established in SSR-1 [4], the effects of these

events on the installation should be evaluated, including all credible secondary effects. The following should also be taken into account:

- (a) When evaluating the effects of external events on the installation, it should be ensured that realistic and credible scenarios are identified and covered by a conservative scenario.
- (b) For evaluations of beyond design basis external events, deterministic and — as far as practicable — probabilistic methods should be used to assess safety margins.

2.28. With regard to the design of nuclear power plants, SSR-2/1 (Rev. 1) [1] states:

“Requirement 24: Common cause failures

“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.”

Similar provisions are established in Requirement 26 of SSR-3 [2] for the design of research reactors and in Requirement 23 of SSR-4 [3] for the design of nuclear fuel cycle facilities.

2.29. With regard to the design of nuclear power plants, Requirement 25 of SSR-2/1 (Rev. 1) [1] states that **“The single failure criterion shall be applied to each safety group incorporated in the plant design.”**⁸ Similar provisions are established in Requirement 25 of SSR-3 [2] for the design of research reactors and in para. 6.92 of SSR-4 [3] for the design of nuclear fuel cycle facilities.

2.30. For design, the single failure criterion is only capable of dealing with random failures. Therefore, the redundancy, which is the ultimate outcome of single failure criteria analysis, might be defeated by common cause failures

⁸ In some States, the probability of occurrence of certain human induced events, such as external explosions or aircraft crashes, is considered very low, and passive components are usually assumed to be designed, manufactured, inspected and maintained to an extremely high quality. Therefore, the single failure non-compliance clause in 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, testing or maintenance, with its associated change in installation configuration, is considered one possible single failure mode in this context. Other States include the single failure criterion for all design basis external events.

associated with external events that have adverse effects over relatively large areas of the site.

2.31. Unless credible, a design basis external event or a beyond design basis external event should be considered in combination with other events that might occur independently, such as other external human induced events, natural phenomena, equipment failures and operator errors. Deterministic and probabilistic evaluations should be used for the determination and evaluation of suitable design combinations.

2.32. A loss of off-site power should be assumed to be coincident with a design basis external event or beyond design basis external event, unless a direct or indirect causal relationship can be excluded. In particular, for external events that are expected to affect the entire site and therefore give rise to a potential for a common cause failure, or for external events that might cause a turbine or reactor trip, a loss of off-site power should be combined with the design basis external event and the beyond design basis external event.

2.33. In the evaluation of design basis external events and beyond design basis external events 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.

2.34. For phenomena of design basis external events and beyond design basis external events that are expected to develop slowly, the possibility of advance warnings and the implementation of precautions should be considered. In such cases, written procedures should be prepared to clearly define the actions to be taken once a warning is received. Consideration should be given to the immediate, medium term and long term effects of design basis external events and beyond design basis external events on off-site and on-site infrastructure and facilities, because non-nuclear on-site infrastructure and facilities may be damaged or destroyed by the external event (e.g. on-site roads or sea harbour landings for supply delivery).

2.35. Off-site infrastructure and assets that, under normal circumstances, are expected to provide various types of support to the nuclear installation might be unavailable. If these conditions could exist for a long period of time, the feasibility of providing support 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 under such conditions, otherwise the provision of off-site support should be excluded from the safety analysis.

2.36. In general, any crediting of mitigatory actions that involve the support of off-site facilities should be based on the analysis of the specific beyond design basis external event and the particular site conditions and should include adequate margins to take account of uncertainties. When presuming the occurrence of external natural and human induced events, no credit for the support of off-site facilities, resources or services (e.g. equipment, electricity supply, firefighting services) is permitted in the short term (see para. 5.17 of SSR-2/1 (Rev. 1) [1]). Site specific conditions should also be taken into consideration when determining the time that would be needed for off-site facilities, resources and services to become available.

2.37. For an ultimate heat sink, the need for make-up of heat transport fluids and the possibility of using auxiliary junctions and injection points for heat removal systems should be examined. Where a limited quantity of heat transport fluids is stored on the site, the capability for make-up should be ensured by one of the following means:

- (a) Protecting the make-up system from external events;
- (b) Providing an adequate quantity of such fluids to allow time to repair the damaged part of the make-up system;
- (c) Providing junctions and injection points to the system, adequately protected from external events, through which additional heat transport fluid can be injected from other on-site sources while the repair takes place.

2.38. Credit for the actions of operating personnel during or after a design basis external event, and the training necessary to perform these actions, should be determined on the basis of the specific external event and its anticipated effects on the site and SSCs. Impediments to the actions of operating personnel include the following:

- (a) Lack of on-site communication;
- (b) Lack of mobility due to soil failures on the site;
- (c) Lack of specialized technical support needed to safely perform a recovery function;
- (d) Inability to perform actions due to failures or malfunctions of SSCs;
- (e) Inaccessibility of areas due to structural damage or changed environmental conditions.