

IAEA Safety Standards

for protecting people and the environment

Seismic Design for Nuclear Installations

Specific Safety Guide

No. SSG-67



IAEA

International Atomic Energy Agency



Documents

Document Sharing Hub

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.

SEISMIC DESIGN FOR NUCLEAR INSTALLATIONS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN	GEORGIA	OMAN
ALBANIA	GERMANY	PAKISTAN
ALGERIA	GHANA	PALAU
ANGOLA	GREECE	PANAMA
ANTIGUA AND BARBUDA	GRENADA	PAPUA NEW GUINEA
ARGENTINA	GUATEMALA	PARAGUAY
ARMENIA	GUYANA	PERU
AUSTRALIA	HAITI	PHILIPPINES
AUSTRIA	HOLY SEE	POLAND
AZERBAIJAN	HONDURAS	PORTUGAL
BAHAMAS	HUNGARY	QATAR
BAHRAIN	ICELAND	REPUBLIC OF MOLDOVA
BANGLADESH	INDIA	ROMANIA
BARBADOS	INDONESIA	RUSSIAN FEDERATION
BELARUS	IRAN, ISLAMIC REPUBLIC OF	RWANDA
BELGIUM	IRAQ	SAINT LUCIA
BELIZE	IRELAND	SAINT VINCENT AND THE GRENADINES
BENIN	ISRAEL	SAMOA
BOLIVIA, PLURINATIONAL STATE OF	ITALY	SAN MARINO
BOSNIA AND HERZEGOVINA	JAMAICA	SAUDI ARABIA
BOTSWANA	JAPAN	SENEGAL
BRAZIL	JORDAN	SERBIA
BRUNEI DARUSSALAM	KAZAKHSTAN	SEYCHELLES
BULGARIA	KENYA	SIERRA LEONE
BURKINA FASO	KOREA, REPUBLIC OF	SINGAPORE
BURUNDI	KUWAIT	SLOVAKIA
CAMBODIA	KYRGYZSTAN	SLOVENIA
CAMEROON	LAO PEOPLE'S DEMOCRATIC REPUBLIC	SOUTH AFRICA
CANADA	LATVIA	SPAIN
CENTRAL AFRICAN REPUBLIC	LEBANON	SRI LANKA
CHAD	LESOTHO	SUDAN
CHILE	LIBERIA	SWEDEN
CHINA	LIBYA	SWITZERLAND
COLOMBIA	LIECHTENSTEIN	SYRIAN ARAB REPUBLIC
COMOROS	LITHUANIA	TAJIKISTAN
CONGO	LUXEMBOURG	THAILAND
COSTA RICA	MADAGASCAR	TOGO
CÔTE D'IVOIRE	MALAWI	TRINIDAD AND TOBAGO
CROATIA	MALAYSIA	TUNISIA
CUBA	MALI	TURKEY
CYPRUS	MALTA	TURKMENISTAN
CZECH REPUBLIC	MARSHALL ISLANDS	UGANDA
DEMOCRATIC REPUBLIC OF THE CONGO	MAURITANIA	UKRAINE
DENMARK	MAURITIUS	UNITED ARAB EMIRATES
DJIBOUTI	MEXICO	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
DOMINICA	MONACO	UNITED REPUBLIC OF TANZANIA
DOMINICAN REPUBLIC	MONGOLIA	UNITED STATES OF AMERICA
ECUADOR	MONTENEGRO	URUGUAY
EGYPT	MOROCCO	UZBEKISTAN
EL SALVADOR	MOZAMBIQUE	VANUATU
ERITREA	MYANMAR	VENEZUELA, BOLIVARIAN REPUBLIC OF
ESTONIA	NAMIBIA	VIET NAM
ESWATINI	NEPAL	YEMEN
ETHIOPIA	NETHERLANDS	ZAMBIA
FIJI	NEW ZEALAND	ZIMBABWE
FINLAND	NICARAGUA	
FRANCE	NIGER	
GABON	NIGERIA	
	NORTH MACEDONIA	
	NORWAY	

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-67

SEISMIC DESIGN FOR NUCLEAR INSTALLATIONS

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

COPYRIGHT NOTICE

All IAEA scientific and technical publications are protected by the terms of the Universal Copyright Convention as adopted in 1952 (Berne) and as revised in 1972 (Paris). The copyright has since been extended by the World Intellectual Property Organization (Geneva) to include electronic and virtual intellectual property. Permission to use whole or parts of texts contained in IAEA publications in printed or electronic form must be obtained and is usually subject to royalty agreements. Proposals for non-commercial reproductions and translations are welcomed and considered on a case-by-case basis. Enquiries should be addressed to the IAEA Publishing Section at:

Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/publications

© IAEA, 2021

Printed by the IAEA in Austria

November 2021

STI/PUB/1949

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.

Title: Seismic design for nuclear installations / International Atomic Energy Agency.

Description: Vienna : International Atomic Energy Agency, 2021. | Series: IAEA safety standards series, ISSN 1020-525X ; no. SSG-67 | Includes bibliographical references.

Identifiers: IAEAL 21-01451 | ISBN 978-92-0-117421-5 (paperback : alk. paper) | ISBN 978-92-0-117521-2 (pdf) | ISBN 978-92-0-117721-6 (epub)

Subjects: LCSH: Nuclear facilities — Design and construction. | Nuclear facilities — Safety measures. | Earthquake resistant design. | Earthquake hazard analysis.

Classification: UDC 621.039.58 | STI/PUB/1949

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.

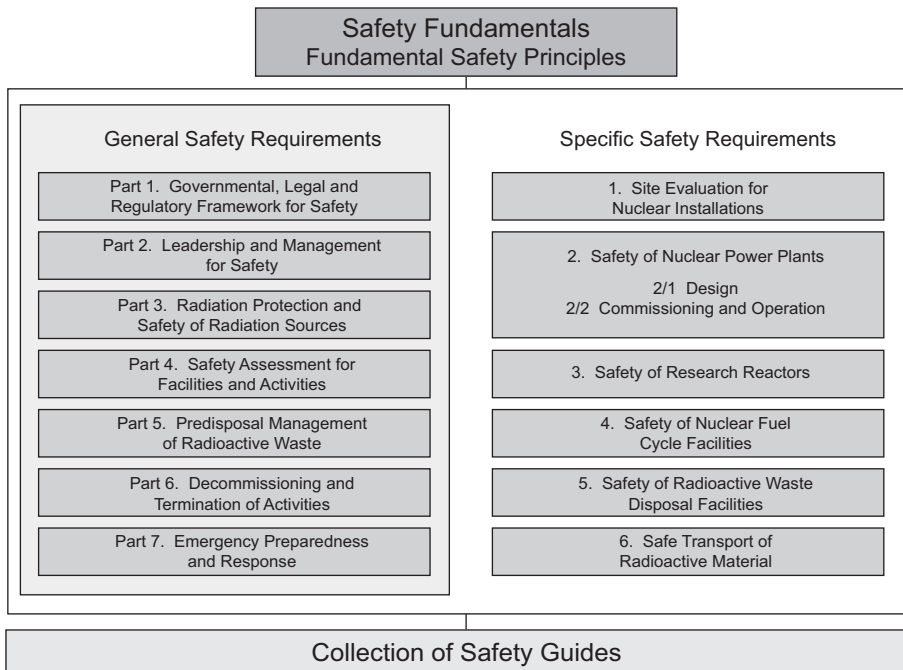


FIG. 1. The long term structure of the IAEA Safety Standards Series.

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.

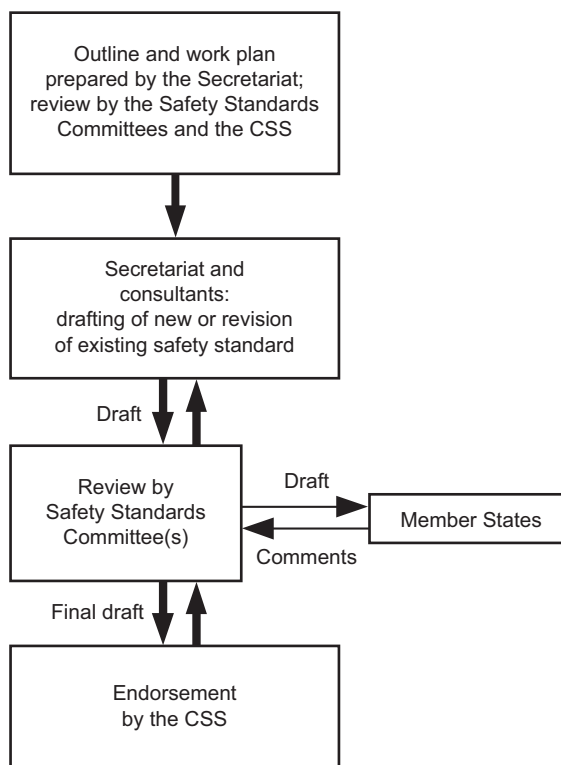


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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.

CONTENTS

1.	INTRODUCTION.....	1
	Background (1.1–1.7).....	1
	Objective (1.8, 1.9).....	2
	Scope (1.10–1.12).....	3
	Structure (1.13).....	3
2.	REQUIREMENTS FOR SEISMIC DESIGN AND GENERAL SEISMIC DESIGN ASPECTS (2.1, 2.2).....	4
	External hazards (2.3).....	5
	Engineering design rules (2.4).....	6
	Design extension conditions (2.5).....	7
	Heat transfer to an ultimate heat sink (2.6).....	7
	Control room (2.7, 2.8).....	8
	Other seismic design aspects (2.9–2.15).....	8
3.	INPUT FOR SEISMIC DESIGN.....	10
	General concepts of seismic design (3.1–3.5).....	10
	Design basis earthquake (3.6–3.26).....	11
	Beyond design basis earthquake (3.27–3.30).....	18
	Seismic categorization for structures, systems and components (3.31–3.40).....	19
	Selection of seismic design and qualification standards (3.41–3.43).....	22
4.	SEISMIC DESIGN OF STRUCTURES, SYSTEMS AND COMPONENTS (4.1).....	22
	Layout of the installation (4.2–4.4).....	23
	Buildings and civil structures (4.5–4.12).....	24
	Engineered earth structures and buried structures (4.13–4.15).....	25
	Seismically isolated structures (4.16–4.23).....	26
	Mechanical equipment (4.24–4.27).....	28
	Storage tanks (4.28).....	29
	Piping (4.29, 4.30).....	30
	Buried pipes (4.31, 4.32).....	30
	Electrical equipment, control and instrumentation (4.33–4.40).....	31

Cable trays and conduits (4.41, 4.42)	32
Heating, ventilation and air-conditioning ducts (4.43)	33
Seismic capacity (4.44–4.49)	34
5. SEISMIC ANALYSIS (5.1)	35
Site response analysis (5.2, 5.3)	35
Structural response (5.4–5.16)	35
Dynamic soil–structure interaction (5.17–5.31)	38
Combination of earthquake loads with other loads (5.32, 5.33)	41
6. SEISMIC QUALIFICATION (6.1, 6.2)	42
Qualification methods (6.3–6.10)	42
Qualification by analysis (6.11–6.18)	44
Qualification by testing (6.19–6.26)	46
Qualification by a combination of analysis and testing (6.27–6.29)	47
Qualification by indirect methods (6.30, 6.31)	48
7. SEISMIC MARGIN TO BE ACHIEVED BY THE DESIGN	49
Concept of seismic margin (7.1–7.4)	49
Adequate seismic margin (7.5, 7.6)	50
Procedures to assess the seismic margin (7.7–7.11)	50
8. SEISMIC INSTRUMENTATION AND POST-EARTHQUAKE ACTIONS	51
Seismic instrumentation (8.1–8.9)	51
Post-earthquake actions (8.10–8.17)	53
9. SEISMIC DESIGN FOR NUCLEAR INSTALLATIONS OTHER THAN NUCLEAR POWER PLANTS (9.1–9.6)	55
10. APPLICATION OF THE MANAGEMENT SYSTEM (10.1–10.6)	58
REFERENCES	61
DEFINITIONS	63
CONTRIBUTORS TO DRAFTING AND REVIEW	65

1. INTRODUCTION

BACKGROUND

1.1. IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1], establishes design requirements for the structures, systems and components (SSCs) of a nuclear power plant. Requirements for the design of research reactors and of nuclear fuel cycle facilities are established in 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], respectively. These publications include requirements for the design to take into account external events, including earthquakes. This Safety Guide provides specific recommendations on the design of nuclear installations to cope with the effects generated by earthquakes.

1.2. This Safety Guide incorporates the following:

- (a) Progress in the design of nuclear installations and in related research, as well as regulatory practices in States, considering the lessons identified from recent strong earthquakes that have affected nuclear installations;
- (b) Recent developments in regulatory practices on application of risk informed and performance based approaches for assessing the safety of nuclear installations;
- (c) The experience and results from seismic design for new nuclear installations in States;
- (d) A more coordinated treatment of the design of nuclear installations against seismically induced geological and geotechnical hazards and concomitant events.

1.3. This Safety Guide provides a clear distinction between (a) the process for assessing the seismic hazards at a specific site and (b) the process for defining the related basis for design and evaluation of the nuclear installations. These processes correspond to (and are performed at) different stages in the lifetime of a nuclear installation. This Safety Guide addresses the interface between these processes so as to bridge any gaps between them and avoid undue overlapping of recommendations.

1.4. Recommendations on the process for assessing the seismic hazards at a specific site, including the definition of the parameters resulting from such an

assessment, are provided in IAEA Safety Standards Series No. SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [4].

1.5. There is an important difference between the seismic design and the seismic safety evaluation of nuclear installations. Seismic design and qualification of SSCs is most often performed at the design stage of the installation, prior to its construction. Seismic safety evaluation can be conducted at the design stage (using data corresponding to the detailed design) and after the installation has been constructed (using as-built and as-operating conditions). There are some exceptions, such as the seismic design of new or replacement components after construction of the installation. Recommendations on the evaluation of existing nuclear installations are provided in IAEA Safety Standards Series No. NS-G-2.13, Evaluation of Seismic Safety for Existing Nuclear Installations [5].

1.6. In several States, designs of new nuclear reactors are being developed generically to meet the needs of many sites across a large geographical area. The intent is that each generic design uses design bases that envelop the potential seismic hazard challenges at all the candidate sites. Confirmation of this is needed when a generic design is nominated for a particular site. At this point, the site specific seismic hazards need to be assessed and compared with the generic seismic hazard design bases to ensure there is an acceptable enveloping margin between them.

1.7. This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-1.6, Seismic Design and Qualification for Nuclear Power Plants¹.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide recommendations on how to meet the safety requirements established in SSR-2/1 (Rev. 1) [1], SSR-3 [2] and SSR-4 [3] in relation to the design aspects of nuclear installations subjected to seismic hazards, defined in accordance with SSG-9 (Rev. 1) [4]. These recommendations focus on the consistent application of methods and procedures, in accordance with best practice, for seismic analysis, design, testing and qualification of SSCs in order that they meet the applicable safety requirements established in Refs [1–3].

¹ INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Design and Qualification for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.6, IAEA, Vienna (2003).

1.9. This Safety Guide is intended for use by organizations involved in the seismic design of nuclear installations, in analysis, verification and review, and in the provision of technical support, as well as by regulatory bodies.

SCOPE

1.10. This Safety Guide addresses all types of nuclear installation, as defined in the IAEA Safety Glossary [6], as follows:

- (a) Nuclear power plants;
- (b) Research reactors (including subcritical and critical assemblies) and any adjoining radioisotope production facilities;
- (c) Storage facilities for spent fuel;
- (d) Facilities for the enrichment of uranium;
- (e) Nuclear fuel fabrication facilities;
- (f) Conversion facilities;
- (g) Facilities for the reprocessing of spent fuel;
- (h) Facilities for the predisposal management of radioactive waste arising from nuclear fuel cycle facilities;
- (i) Nuclear fuel cycle related research and development facilities.

1.11. Recommendations for nuclear power plants are applicable to other nuclear installations by means of a graded approach, whereby these recommendations are applied in accordance with the potential radiological consequences of the failure of the installation when subjected to seismic loads. The recommended graded approach is to start with the recommendations relating to nuclear power plants and adjust these to installations associated with lesser radiological consequences. If no such adjustment is justified, the recommendations relating to nuclear power plants are to be applied.

1.12. This Safety Guide is intended to be applied to the design and construction of new nuclear installations. Assessment of the seismic safety of an existing nuclear installation is beyond the scope of this Safety Guide and should follow the recommendations provided in NS-G-2.13 [5].

STRUCTURE

1.13. The structure of this Safety Guide follows the general workflow of seismic design and qualification. Section 2 describes the safety requirements

for addressing external hazards and the effects of seismic events and provides recommendations on general seismic design aspects. Section 3 provides recommendations relating to input for seismic design and qualification, including the design basis earthquake, the data obtained from the site characterization and the seismic categorization of SSCs. Section 4 provides recommendations on good design practices for layout, structures and different categories of component. For each category, the key seismic design issues derived from earthquake experience are identified and current best practice in seismic design is described. Section 5 provides recommendations on seismic analysis, and Section 6 provides recommendations on seismic qualification by analysis, by testing and by indirect methods. Section 7 provides recommendations on assessing the seismic margin to be ensured by the design. Section 8 provides recommendations on seismic instrumentation and suitable monitoring procedures and their relation to design assumptions and post-earthquake actions. Section 9 provides guidance on using the recommendations of this Safety Guide for nuclear installations other than nuclear power plants. Section 10 provides recommendations on the application of the management system and on project management and peer reviews. A list of definitions specific to this Safety Guide is also provided.

2. REQUIREMENTS FOR SEISMIC DESIGN AND GENERAL SEISMIC DESIGN ASPECTS

2.1. Requirements 15 and 16 of IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [7], require that the seismic hazards associated with a site for a nuclear installation be evaluated to serve as an input to the seismic design of the installation.

2.2. The requirements relevant to seismic design for nuclear power plants are established in SSR-2/1 (Rev. 1) [1]. For seismic design for research reactors and for nuclear fuel cycle facilities, relevant requirements are established in SSR-3 [2] and SSR-4 [3], respectively. All of these Safety Requirements publications stress the importance of applying a graded approach. Where no specific safety requirements for seismic 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 9.

EXTERNAL HAZARDS

2.3. With regard to considering external hazards such as earthquakes 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...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.”

2.8. 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 SEISMIC DESIGN ASPECTS

2.9. The implementation of the relevant safety requirements in the design of a nuclear installation against seismic events should ensure that Principle 8 of IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [8], on the prevention of accidents is applied.

2.10. The seismic design of items important to safety should be based on the seismic hazards determined during the site evaluation process for the nuclear installation, conducted in accordance with the requirements established in SSR-1 [7] and the recommendations provided in SSG-9 (Rev. 1) [4]. Specifically, the site specific vibratory ground motions assessed using deterministic and/or probabilistic approaches should be available and should be used to assess the adequacy of the

design basis earthquake for the nuclear installation, as recommended in Section 3 of this Safety Guide.

2.11. Seismic design should consider the influence of the layout of the plant and of the detailed arrangements and layout of SSCs. Specific recommendations are provided in Section 4 of this Safety Guide.

2.12. The following specific aspects should be considered in the seismic design of nuclear installations:

- (a) Protection against common cause failure of SSCs in the event of an earthquake affecting all units in a multiple unit site (seismic events can lead to serious challenges to the multiple layers of defence in depth, through common cause failures);
- (b) Minimization of seismic interaction effects;
- (c) Provision of adequate seismic margins and avoidance of cliff edge effects²;
- (d) Compliance with proven engineering design rules, as specified in relevant national and international codes and standards.

2.13. Special consideration should be given to the need to provide an adequate seismic margin for those SSCs ultimately required to prevent an early radioactive release or a large radioactive release in the event of an earthquake exceeding those considered for design purposes.³ The recommendations in Section 3 of this Safety Guide are provided to determine the beyond design basis earthquake and the categorization of the SSCs to be designed or evaluated against such an event; the applicable performance criteria are considered in Sections 7 and 9.

2.14. When the recommendations of this Safety Guide are applied to the seismic design of nuclear installations other than nuclear power plants, engineering judgement and a graded approach should be used to assess the applicability of the recommendations, in accordance with the specific safety objectives defined for the type of installation concerned. Further guidance is provided in Section 9.

2.15. The design process for a nuclear installation should be well structured and should be conducted under the rules, procedures and conditions of proper

² 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.

³ For seismic events, it is assumed that early warnings are not possible and that there is a high probability of combinations with other seismic induced hazards (e.g. internal fires, floods).

project management. Requirements for the implementation of an integrated management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [9], and specific recommendations are provided in IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [10]. The seismic design process should be integrated into the management system (see Section 10) and should include adequate peer review.

3. INPUT FOR SEISMIC DESIGN

GENERAL CONCEPTS OF SEISMIC DESIGN

3.1. In the IAEA Safety Glossary [6], design is defined as the process and the result of developing a concept, detailed plans, supporting calculations and specifications for a facility and its parts. Equipment qualification is defined as the generation and maintenance of evidence to ensure that equipment will operate on demand, under specified service conditions, to meet system performance requirements. Seismic qualification refers to a form of equipment qualification that relates to conditions that could be encountered in the event of an earthquake.

3.2. In this Safety Guide, seismic design is the process of designing a nuclear installation to cope with the effects of the hazards generated by a seismic event, in accordance with specified performance criteria and in compliance with the requirements indicated in Section 2. Therefore, seismic qualification is part of the process of seismic design and refers to equipment qualification to comply with these objectives.

3.3. Earthquakes generate several direct and indirect phenomena. These include vibratory ground motions from associated geological and geotechnical hazards, permanent ground deformation (e.g. soil liquefaction, slope instability, tectonic and non-tectonic subsidence, cavities leading to ground collapse, settlements), and concomitant events such as seismically induced fires and floods.

3.4. If the characteristics of some geological and geotechnical hazards are such that satisfactory engineering solutions to protect against them have not been identified, the site should be deemed unsuitable, as recommended in SSG-9 (Rev. 1) [4] and IAEA Safety Standards Series No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants [11].