IAEA Safety Standards

for protecting people and the environment

Safety of Nuclear Power Plants: Design

Specific Safety Requirements

No. SSR-2/1 (Rev. 1)

IAEA
International Atomic Energy Agency

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

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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.

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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**.

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SAFETY OF NUCLEAR POWER PLANTS: DESIGN

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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. SSR-2/1 (Rev. 1)

SAFETY OF NUCLEAR POWER PLANTS: DESIGN

SPECIFIC SAFETY REQUIREMENTS

This publication includes a CD-ROM containing the IAEA Safety Glossary: 2007 Edition (2007) and the Fundamental Safety Principles (2006), each in Arabic, Chinese, English, French, Russian and Spanish versions. The CD-ROM is also available for purchase separately. See: http://www-pub.iaea.org/books

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FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt... standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

PREFACE

The accident at the Fukushima Daiichi nuclear power plant in Japan followed the Great East Japan Earthquake and Tsunami of 11 March 2011. The IAEA Action Plan on Nuclear Safety (GOV/2011/59-GC(55)/14) was developed in response to the Fukushima Daiichi accident[1] and was approved by the IAEA Board of Governors and endorsed by the IAEA General Conference in September 2011 (GC(55)/RES/9). It includes an action headed: Review and strengthen IAEA Safety Standards and improve their implementation.

This action called upon the Commission on Safety Standards (CSS) and the IAEA Secretariat to review, and revise as necessary, the relevant IAEA safety standards in a prioritized sequence, and called on Member States to utilize the IAEA safety standards as broadly and effectively as possible.

This review covered, among other topics, the regulatory structure, emergency preparedness and response, and nuclear safety and engineering aspects (site selection and evaluation, assessment of extreme natural hazards, including their combined effects, management of severe accidents, station blackout, loss of heat sink, accumulation of explosive gases, the behaviour of nuclear fuel and the safety of spent fuel storage).

In 2011, the Secretariat commenced such a review of Safety Requirements publications in the IAEA Safety Standards Series on the basis of information that was available on the Fukushima Daiichi accident, including two reports from the Government of Japan, issued in June 2011 and September 2011, the report of the IAEA International Fact Finding Expert Mission conducted in Japan from 24 May to 2 June 2011, and a letter from the Chair of the International Nuclear Safety Group (INSAG) to the Director General dated 26 July 2011. As a priority, the Secretariat reviewed the Safety Requirements publications applicable to nuclear power plants and to the storage of spent fuel.

The review consisted first of a comprehensive analysis of the findings of these reports. In the light of the results of this analysis, the Safety Requirements publications were then examined in a systematic manner in order to decide whether amendments were desirable to reflect any of these findings.

On that basis, the CSS approved, at its meeting in October 2012, a proposal for a revision process by amendment for the following five Safety Requirements publications: Governmental, Legal and Regulatory Framework for Safety (IAEA Safety Standards Series No. GSR Part 1, 2010); Safety Assessment for Facilities

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[1] For further information, see INTERNATIONAL ATOMIC ENERGY AGENCY, The Fukushima Daiichi Accident: Report by the Director General, IAEA, Vienna (2015).

and Activities (GSR Part 4, 2009); Safety of Nuclear Power Plants: Design (SSR-2/1. 2012): Safety of Nuclear Power Plants: Commissioning and Operation (SSR-2/2. 2011); and Site Evaluation for Nuclear Installations (NS-R-3, 2003).

Additional inputs were considered in preparing the draft text of the proposed amendments to these five safety standards in 2012 and 2013, including the findings of the IAEA International Experts Meetings and presentations made at the Second Extraordinary Meeting of the Contracting Parties to the Convention on Nuclear Safety, in August 2012. Several national and regional reports were also considered.

On the review of the Safety Requirements, the Commission's conclusion, reflected in a letter from the CSS Chair to the Director General dated 6 January 2014, was that:

> "the review has confirmed so far the adequacy of the current Safety Requirements. The review revealed no significant areas of weakness, and just a small set of amendments were proposed to strengthen the requirements and facilitate their implementation. The CSS believes that the IAEA Safety Standards should be enhanced mainly through the well-established review and revision process that has been in use for some years. At the same time, CSS members highlighted that the basis for the review and revision of the IAEA Safety Standards should not be limited to the lessons of the Fukushima Daiichi accident. This basis should also include other operating experience from elsewhere as well as information gained from advances in research and development. The CSS also stressed that greater attention needs to be paid to the implementation of IAEA safety standards by and in Member States."

The draft amendments were reviewed by the Secretariat in consultants meetings, as well as by the Nuclear Safety Standards Committee, the Radiation Safety Standards Committee, the Transport Safety Standards Committee and the Waste Safety Standards Committee, in the first half of 2013. They were also presented for information to the Nuclear Security Guidance Committee in 2013. The draft amendments were then submitted to IAEA Member States for comment and revised in consultants meetings in the light of comments received. The proposed amendments were then approved by all four Safety Standards Committees at their meetings in June and July 2014, and were endorsed by the CSS at its meeting in November 2014.

The revisions to SSR-2/1 relate to the following main areas:

— Prevention of severe accidents by strengthening the design basis for the plant;

— Prevention of unacceptable radiological consequences of a severe accident for the public and the environment;
— Mitigation of the consequences of a severe accident to avoid or to minimize radioactive contamination off the site.

Amendments have been made to specific paragraphs, as outlined below. New paragraphs have been added; these are indicated by means of an uppercase letter (A, B, ...). In addition, where a paragraph has been deleted, this is indicated in the text.

The following requirements and paragraphs have been amended or added in this revised edition: 2.13, 4.13A, 5.1, Requirement 17, 5.15A, 5.15B, 5.17, 5.18, 5.20, 5.21, 5.21A, 5.22, Requirement 19, 5.27, 5.28, 5.31, 5.31A, 5.55, Requirement 33, 5.63, 5.73, 5.75, 5.76, Requirement 53, 6.19A, 6.19B, 6.28A, 6.28B, 6.39, 6.40A, Requirement 67, 6.42, Requirement 68, 6.43, 6.44A, 6.44B, 6.44C, 6.44D, 6.45A, 6.68 and 6.68A. Some amendments of an editorial nature have also been made.

A table of changes made is available upon request to the IAEA (Safety.Standards@iaea.org).

The Board, at its meeting starting on 2 March 2015, established as an IAEA safety standard — in accordance with Article III.A.6 of the Statute of the IAEA — the draft of this revised Safety Requirements publication, and authorized the Director General to promulgate these revised safety requirements and to issue them as a Safety Requirements publication in the IAEA Safety Standards Series.

The 59th IAEA General Conference, in September 2015, encouraged Member States to implement measures nationally, regionally and internationally to ensure nuclear, radiation, transport and waste safety, as well as emergency preparedness, taking full account of IAEA safety standards; requested the IAEA to continuously review, strengthen and implement as broadly and effectively as possible the IAEA safety standards; and supported the CSS and the Safety Standards Committees in their review of the relevant safety standards in the light of the Fukushima Daiichi accident, as well as the lessons identified in the IAEA report on the Fukushima Daiichi accident[1].

The General Conference requested the Secretariat:

> "to continue its close cooperation with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP) and other relevant organizations in the development of safety standards, including, but not limited to, the protection of the environment".

The 59th IAEA General Conference also encouraged Member States to use the IAEA safety standards in their national regulatory programmes, as appropriate, and noted the need to consider the periodic review of national regulations and guidance against internationally established standards and guidance, and to report on progress in appropriate international fora such as review meetings under the terms of the relevant safety conventions.

The General Conference further encouraged Member States to ensure regular self-assessments of their domestic nuclear, radiation, transport and waste safety, as well as emergency preparedness, using the IAEA self-assessment tools and taking into account relevant IAEA safety standards.

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 measures[1] 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.

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

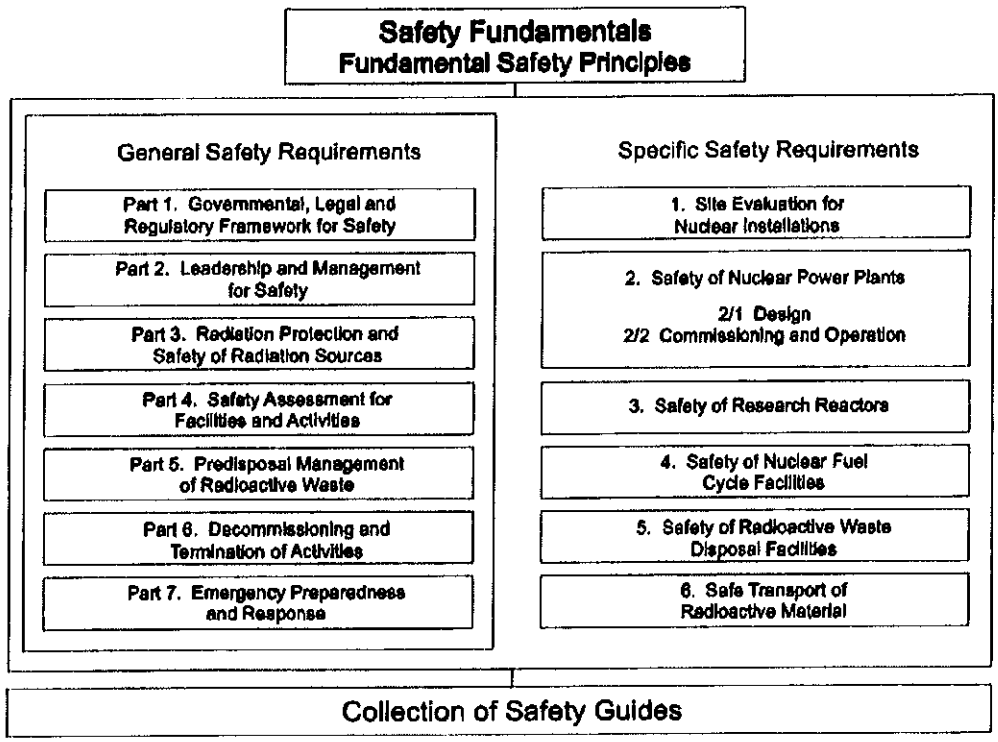

FIG. 1. The long term structure of the IAEA Safety Standards Series.

Safety Guides

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

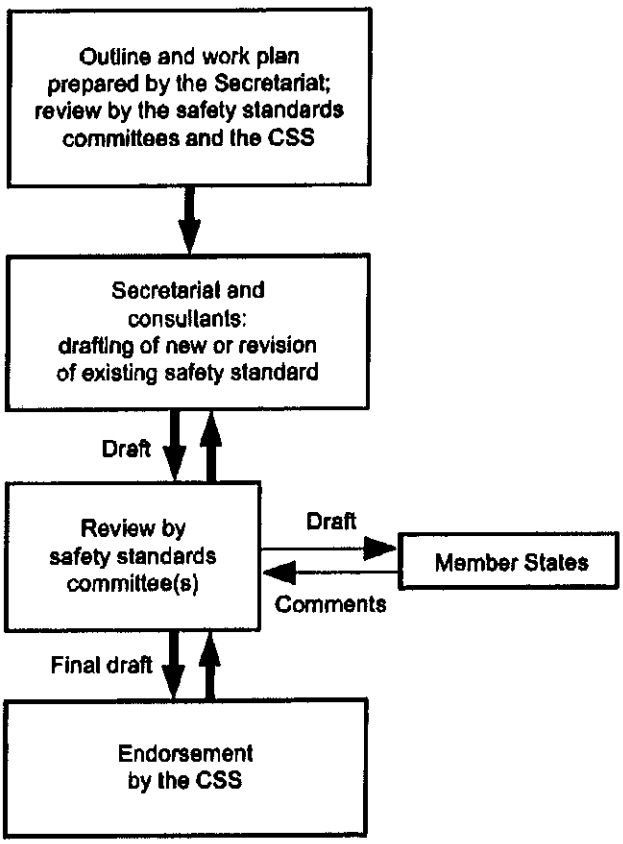

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. 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 http://www-ns.iaea.org/standards/safety-glossary.htm). 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

BACKGROUND

1.1. The present publication supersedes the Safety Requirements publication Safety of Nuclear Power Plants: Design.[1] which was issued in 2012 as IAEA Safety Standards Series No. SSR-2/1. Account has been taken of the Fundamental Safety Principles [1], published in 2006. Requirements for nuclear safety are intended to ensure "the highest standards of safety that can reasonably be achieved" for the protection of workers, the public and the environment from harmful effects of ionizing radiation that could arise from nuclear power plants and other nuclear facilities [1]. It is recognized that technology and scientific knowledge advance, and that nuclear safety and the adequacy of protection against radiation risks need to be considered in the context of the present state of knowledge. Safety requirements will change over time; this Safety Requirements publication reflects the present consensus.

1.2. The designs of many existing nuclear power plants, as well as the designs for new nuclear power plants, have been enhanced to include additional measures to mitigate the consequences of complex accident sequences involving multiple failures and of severe accidents. Complementary systems and equipment with new capabilities have been backfitted to many existing nuclear power plants to aid in the prevention of severe accidents and the mitigation of their consequences. Guidance on the mitigation of the consequences of severe accidents has been provided at most existing nuclear power plants. The design of new nuclear power plants now explicitly includes the consideration of severe accident scenarios and strategies for their management. Requirements related to the State system of accounting for, and control of, nuclear material and security related requirements are also taken into account in the design of nuclear power plants. Integration of safety measures and security measures will help to ensure that neither compromise the other.

1.3. It might not be practicable to apply all the requirements of this Safety Requirements publication to nuclear power plants that are already in operation or under construction. In addition, it might not be feasible to modify designs that have already been approved by regulatory bodies. For the safety analysis of such

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1, IAEA, Vienna (2012).

designs, it is expected that a comparison will be made with the current standards, for example as part of the periodic safety review for the plant, to determine whether the safe operation of the plant could be further enhanced by means of reasonably practicable safety improvements.

OBJECTIVE

1.4. This publication establishes design requirements for the structures, systems and components of a nuclear power plant, as well as for procedures and organizational processes important to safety that are required to be met for safe operation and for preventing events that could compromise safety, or for mitigating the consequences of such events, were they to occur.

1.5. This publication is intended for use by organizations involved in design, manufacture, construction, modification, maintenance, operation and decommissioning for nuclear power plants, in analysis, verification and review, and in the provision of technical support, as well as by regulatory bodies.

SCOPE

1.6. It is expected that this publication will be used primarily for land based stationary nuclear power plants with water cooled reactors designed for electricity generation or for other heat production applications (such as district heating or desalination). This publication may also be applied, with judgement, to other reactor types, to determine the requirements that have to be considered in developing the design.

1.7. This publication does not address:

(a) Requirements that are specifically covered in other IAEA Safety Requirements publications (e.g. IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [2]);
(b) Matters relating to nuclear security or to the State system of accounting for, and control of, nuclear material;
(c) Conventional industrial safety that under no circumstances could affect the safety of the nuclear power plant;
(d) Non-radiological impacts arising from the operation of nuclear power plants.

1.8. Terms in this publication are to be understood as defined and explained in the IAEA Safety Glossary [3], unless otherwise stated here (see Definitions).

STRUCTURE

1.9. This Safety Requirements publication follows the relationship between the safety objective and safety principles, and between requirements for nuclear safety functions and design criteria for safety. Section 2 elaborates on the safety objective, safety principles and concepts that form the basis for deriving the safety function requirements that must be met for the nuclear power plant, as well as the safety design criteria. Sections 3–6 establish numbered overarching requirements (shown in bold type), with additional requirements as appropriate in the paragraphs that follow them. Section 3 establishes the general requirements to be satisfied by the design organization in the management of safety in the design process. Section 4 establishes: requirements for principal technical design criteria for safety, including requirements for the fundamental safety functions, the application of defence in depth and provision for construction; requirements for interfaces of safety with nuclear security and with the State system of accounting for, and control of, nuclear material; and requirements for ensuring that radiation risks arising from the plant are maintained as low as reasonably achievable. Section 5 establishes requirements for general plant design that supplement the requirements for principal technical design criteria to ensure that safety objectives are met and the safety principles are applied. The requirements for general plant design apply to all items (i.e. structures, systems and components) important to safety. Section 6 establishes requirements for the design of specific plant systems such as the reactor core, reactor coolant systems, containment system, and instrumentation and control systems.

2. APPLYING THE SAFETY PRINCIPLES AND CONCEPTS

2.1. The Fundamental Safety Principles [1] establish one fundamental safety objective and ten safety principles that provide the basis for requirements and measures for the protection of people and the environment against radiation risks and for the safety of facilities and activities that give rise to radiation risks.

2.2. This fundamental safety objective has to be achieved, and the ten safety principles have to be applied, without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks. To ensure that nuclear power plants are operated and activities are conducted so as to achieve the highest standards of safety that can reasonably be achieved, measures have to be taken to achieve the following (see para. 2.1 of the Fundamental Safety Principles [1]):

(a) To control the radiation exposure of people and radioactive releases to the environment in operational states;
(b) To restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source, spent nuclear fuel, radioactive waste or any other source of radiation at a nuclear power plant;
(c) To mitigate the consequences of such events if they were to occur.

2.3. The fundamental safety objective applies for all stages in the lifetime of a nuclear power plant, including planning, siting, design, manufacture, construction, commissioning and operation, as well as decommissioning. This includes the associated transport of radioactive material and the management of spent nuclear fuel and radioactive waste (see para. 2.2 of the Fundamental Safety Principles [1]).

2.4. Paragraph 2.3 of the Fundamental Safety Principles [1] states that:

> "Ten safety principles have been formulated, on the basis of which safety requirements are developed and safety measures are to be implemented in order to achieve the fundamental safety objective. The safety principles form a set that is applicable in its entirety; although in practice different principles may be more or less important in relation to particular circumstances, the appropriate application of all relevant principles is required."

2.5. This Safety Requirements publication establishes requirements that apply those safety principles, which are particularly important in the design of nuclear power plants.

RADIATION PROTECTION IN DESIGN

2.6. In order to satisfy the safety principles, it is required to ensure that for all operational states of a nuclear power plant and for any associated activities, doses

from exposure to radiation within the installation or exposure due to any planned radioactive release from the installation are kept below the dose limits and kept as low as reasonably achievable. In addition, it is required to take measures for mitigating the radiological consequences of any accidents, if they were to occur.

2.7. To apply the safety principles, it is also required that nuclear power plants be designed and operated so as to keep all sources of radiation under strict technical and administrative control. However, this principle does not preclude limited exposures or the release of authorized amounts of radioactive substances to the environment from nuclear power plants in operational states. Such exposures and radioactive releases are required to be strictly controlled and to be kept as low as reasonably achievable, in compliance with regulatory and operational limits as well as radiation protection requirements [4].

SAFETY IN DESIGN

2.8. To achieve the highest level of safety that can reasonably be achieved in the design of a nuclear power plant, measures are required to be taken to do the following, consistent with national acceptance criteria and safety objectives [1]:

(a) To prevent accidents with harmful consequences resulting from a loss of control over the reactor core or over other sources of radiation, and to mitigate the consequences of any accidents that do occur;
(b) To ensure that for all accidents taken into account in the design of the installation, any radiological consequences would be below the relevant limits and would be kept as low as reasonably achievable;
(c) To ensure that the likelihood of occurrence of an accident with serious radiological consequences is extremely low and that the radiological consequences of such an accident would be mitigated to the fullest extent practicable.

2.9. To demonstrate that the fundamental safety objective [1] is achieved in the design of a nuclear power plant, a comprehensive safety assessment [2] of the design is required to be carried out. Its objective is to identify all possible sources of radiation and to evaluate possible doses that could be received by workers at the installation and by members of the public, as well as possible effects on the environment, as a result of operation of the plant. The safety assessment is required in order to examine: (i) normal operation of the plant; (ii) the performance of the plant in anticipated operational occurrences; and (iii) accident conditions. On the basis of this analysis, the capability of the design

to withstand postulated initiating events and accidents can be established, the effectiveness of the items important to safety can be demonstrated and the inputs (prerequisites) for emergency planning can be established.

2.10. Measures are required to be taken to control exposure for all operational states at levels that are as low as reasonably achievable and to minimize the likelihood of an accident that could lead to the loss of control over a source of radiation. Nevertheless, there will remain a possibility that an accident could happen. Measures are required to be taken to ensure that the radiological consequences of an accident would be mitigated. Such measures include the provision of safety features and safety systems, the establishment of accident management procedures by the operating organization and, possibly, the establishment of off-site protective actions by the appropriate authorities, supported as necessary by the operating organization, to mitigate exposures if an accident occurs.

2.11. The design for safety of a nuclear power plant applies the safety principle that practical measures must be taken to mitigate the consequences for human life and health and for the environment of nuclear or radiation accidents (Principle 8 of the Fundamental Safety Principles [1]). Plant event sequences that could result in high radiation doses or in a large radioactive release have to be 'practically eliminated'[2] and plant event sequences with a significant frequency of occurrence have to have no, or only minor, potential radiological consequences. An essential objective is that the necessity for off-site protective actions to mitigate radiological consequences be limited or even eliminated in technical terms, although such measures might still be required by the responsible authorities.

THE CONCEPT OF DEFENCE IN DEPTH

2.12. The primary means of preventing accidents in a nuclear power plant and mitigating the consequences of accidents if they do occur is the application of the concept of defence in depth [1, 5, 6]. This concept is applied to all safety related activities, whether organizational, behavioural or design related, and whether in full power, low power or various shutdown states. This is to ensure that all safety related activities are subject to independent layers of provisions so that if a failure were to occur, it would be detected and compensated for or

[2] The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise.

corrected by appropriate measures. Application of the concept of defence in depth throughout design and operation provides protection against anticipated operational occurrences and accidents, including those resulting from equipment failure or human induced events within the plant, and against consequences of events that originate outside the plant.

2.13. Paragraph 3.31 of the Fundamental Safety Principles [1] states that:

> "Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment. If one level of protection or barrier were to fail, the subsequent level or barrier would be available.... The independent effectiveness of the different levels of defence is a necessary element of defence in depth."

There are five levels of defence:

(1) The purpose of the first level of defence is to prevent deviations from normal operation and the failure of items important to safety. This leads to requirements that the plant be soundly and conservatively sited, designed, constructed, maintained and operated in accordance with quality management and appropriate and proven engineering practices. To meet these objectives, careful attention is paid to the selection of appropriate design codes and materials, and to the quality control of the manufacture of components and construction of the plant, as well as to its commissioning. Design options that reduce the potential for internal hazards contribute to the prevention of accidents at this level of defence. Attention is also paid to the processes and procedures involved in design, manufacture, construction, and in-service inspection, maintenance and testing, to the ease of access for these activities, and to the way the plant is operated and to how operating experience is utilized. This process is supported by a detailed analysis that determines the requirements for operation and maintenance of the plant and the requirements for quality management for operational and maintenance practices.

(2) The purpose of the second level of defence is to detect and control deviations from normal operational states in order to prevent anticipated operational occurrences at the plant from escalating to accident conditions. This is in recognition of the fact that postulated initiating events are likely to occur over the operating lifetime of a nuclear power plant, despite the care taken to prevent them. This second level of defence necessitates the provision of specific systems and features in the design, the confirmation

of their effectiveness through safety analysis, and the establishment of operating procedures to prevent such initiating events, or otherwise to minimize their consequences, and to return the plant to a safe state.

(3) For the third level of defence, it is assumed that, although very unlikely, the escalation of certain anticipated operational occurrences or postulated initiating events might not be controlled at a preceding level and that an accident could develop. In the design of the plant, such accidents are postulated to occur. This leads to the requirement that inherent and/or engineered safety features, safety systems and procedures be capable of preventing damage to the reactor core or preventing radioactive releases requiring off-site protective actions and returning the plant to a safe state.

(4) The purpose of the fourth level of defence is to mitigate the consequences of accidents that result from failure of the third level of defence in depth. This is achieved by preventing the progression of such accidents and mitigating the consequences of a severe accident. The safety objective in the case of a severe accident is that only protective actions that are limited in terms of lengths of time and areas of application would be necessary and that off-site contamination would be avoided or minimized. Event sequences that would lead to an early radioactive release or a large radioactive release[3] are required to be 'practically eliminated'[4].

(5) The purpose of the fifth and final level of defence is to mitigate the radiological consequences of radioactive releases that could potentially result from accidents. This requires the provision of adequately equipped emergency response facilities and emergency plans and emergency procedures for on-site and off-site emergency response.

2.14. A relevant aspect of the implementation of defence in depth for a nuclear power plant is the provision in the design of a series of physical barriers, as well as a combination of active, passive and inherent safety features that contribute to the effectiveness of the physical barriers in confining radioactive material at specified locations. The number of barriers that will be necessary will depend upon the initial source term in terms of the amount and isotopic composition of

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

[4] The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise.

radionuclides, the effectiveness of the individual barriers, the possible internal and external hazards, and the potential consequences of failures.

MAINTAINING THE INTEGRITY OF DESIGN OF THE PLANT THROUGHOUT THE LIFETIME OF THE PLANT

2.15. The design, construction and commissioning of a nuclear power plant might be shared between a number of organizations: the architect–engineer, the vendor of the reactor and its supporting systems, the suppliers of major components, the designers of electrical systems, and the suppliers of other systems that are important to the safety of the plant.

2.16. The prime responsibility for safety rests with the person or organization responsible for facilities and activities that give rise to radiation risks (i.e. the operating organization) [1]. In 2003, the International Nuclear Safety Advisory Group suggested that the operating organization could set up a formal process to maintain the integrity of design of the plant throughout the lifetime of the plant (i.e. during the operating lifetime and into the decommissioning stage) [7]. A formally designated entity within the operating organization would take responsibility for this process.

2.17. In practice, the design of a nuclear power plant is complete only when the full plant specification (including site details) is produced for its procurement and licensing. Reference [7] emphasizes the need for a formally designated entity that has overall responsibility for the design process and is responsible for approving design changes and for ensuring that the requisite knowledge is maintained. Reference [7] also introduces the concept of 'responsible designers', to whom this formally designated entity could assign specific responsibilities for the design of parts of the plant. Prior to an application for authorization of a plant, the responsibility for the design will rest with the design organization (e.g. the vendor). Once an application for authorization of a plant has been made, the prime responsibility for safety will lie with the applicant, although detailed knowledge of the design will rest with the responsible designers. This balance will change as the plant is put into operation, since much of this detailed knowledge, such as the knowledge embodied in the safety analysis report, design manuals and other design documentation, will be transferred to the operating organization. To facilitate this transfer of knowledge, the structure of the formally designated entity that has overall responsibility for the design process would be established at an early stage.

2.18. The management system requirements that are placed on this formally designated entity would also apply to the responsible designers. However, the overall responsibility for maintaining the integrity of design of the plant would rest with the formally designated entity, and hence, ultimately, with the operating organization.

3. MANAGEMENT OF SAFETY IN DESIGN

Requirement 1: Responsibilities in the management of safety in plant design

An applicant for a licence to construct and/or operate a nuclear power plant shall be responsible for ensuring that the design submitted to the regulatory body meets all applicable safety requirements.

3.1. All organizations, including the design organization[5], engaged in activities important to the safety of the design of a nuclear power plant shall be responsible for ensuring that safety matters are given the highest priority.

Requirement 2: Management system for plant design

The design organization shall establish and implement a management system for ensuring that all safety requirements established for the design of the plant are considered and implemented in all phases of the design process and that they are met in the final design.

3.2. The management system[6] shall include provision for ensuring the quality of the design of each structure, system and component, as well as of the overall design of the nuclear power plant, at all times. This includes the means for identifying and correcting design deficiencies, for checking the adequacy of the design and for controlling design changes.

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[5] The design organization is the organization responsible for preparation of the final detailed design of the plant to be built.

[6] Requirements on the management system are established in IAEA Safety Standards Series No. GS-R-3, The Management System for Facilities and Activities [8].

Safety through international standards

"Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them."

Yukiya Amano
Director General

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