IAEA Safety Standards
for protecting people and the environment

Design of Fuel Handling and Storage Systems for Nuclear Power Plants

Specific Safety Guide
No. SSG-63

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.

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DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR NUCLEAR POWER PLANTS

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

IAEA SAFETY STANDARDS SERIES No. SSG-63

DESIGN OF FUEL HANDLING AND STORAGE SYSTEMS FOR NUCLEAR POWER PLANTS

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FOREWORD

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.

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.

Safety Guides

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

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

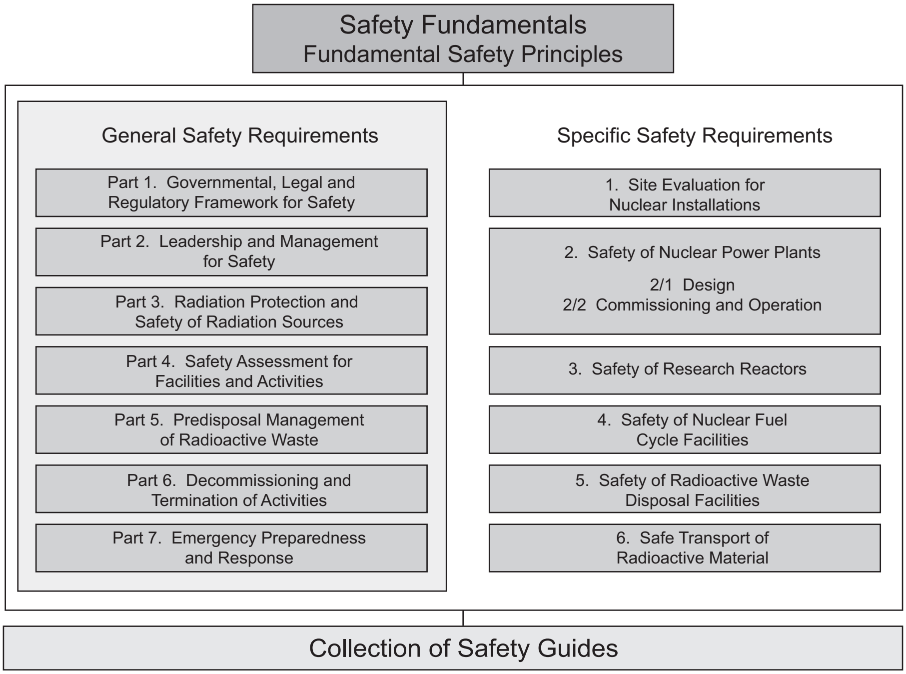

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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.

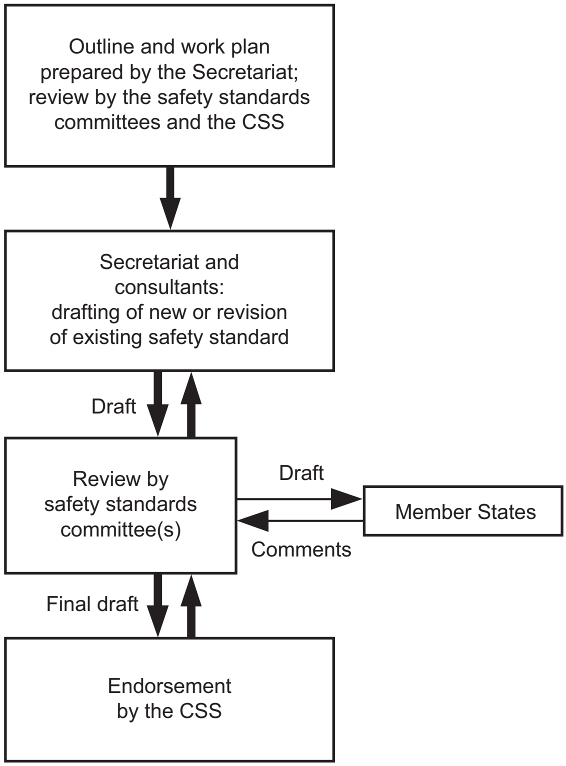

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 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. This Safety Guide provides recommendations on how to meet the requirements established in IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [1], in relation to the design of fuel handling and storage systems for nuclear power plants.

1.2. This Safety Guide is a revision of IAEA Safety Standards Series No. NS-G-1.4, Design of Fuel Handling and Storage Systems for Nuclear Power Plants[1], which it supersedes.

1.3. This Safety Guide takes into account lessons from the accident at the Fukushima Daiichi nuclear power plant in 2011, in particular in respect of the application of strengthened defence in depth to the design of fuel handling and storage systems in nuclear power plants.

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations for the design of fuel handling and storage systems in nuclear power plants, in order to meet the requirements established in SSR-2/1 (Rev. 1) [1] for these systems.

SCOPE

1.5. This Safety Guide applies primarily to land based stationary nuclear power plants with water cooled reactors. All statements are applicable to light water reactors (i.e. pressurized water reactors, boiling water reactors) and are generally applicable to pressurized heavy water reactors unless otherwise specified. The concepts in this Safety Guide can be applied, with judgement, to other reactor types (e.g. gas cooled reactors, small and modular reactors, innovative reactors).

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Fuel Handling and Storage Systems for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.4, IAEA, Vienna (2003).

1.6. This Safety Guide addresses the design aspects of handling and storage systems for fuel that remains part of the operational activities of a nuclear reactor. From this perspective, this Safety Guide covers the following stages of fuel handling and storage in a nuclear power plant:

(a) Receipt of fresh fuel;
(b) Storage and inspection of fresh fuel before use;
(c) Transfer of fresh fuel into the reactor;
(d) Removal of irradiated fuel from the reactor and transfer of irradiated fuel to the spent fuel pool;
(e) Reinsertion of irradiated fuel from the spent fuel pool into the reactor, as necessary;
(f) Storage, inspection and repair of irradiated or spent fuel in the spent fuel pool, and the preparation for the removal of this fuel from the spent fuel pool;
(g) Handling of fuel casks in the spent fuel pool;
(h) Transfer of spent fuel casks.

Handling and storage systems for spent fuel that does not remain part of the operational activities of a nuclear reactor (e.g. as needed for interim wet or dry storage) are addressed in IAEA Safety Standards Series No. SSG-15 (Rev. 1), Storage of Spent Nuclear Fuel [2].

1.7. Limited consideration is given in this Safety Guide to the handling and storage of certain irradiated core components, such as reactivity control devices.

1.8. This Safety Guide is intended for application to uranium dioxide fuels (natural, enriched or reprocessed uranium) and plutonium blended uranium dioxide fuel (mixed oxide fuel) with metal cladding.

1.9. This Safety Guide is primarily intended for application to fuel handling and storage systems for new nuclear power plants. For nuclear power plants designed to earlier standards, it is expected that in the safety assessments of such designs, a comparison will be made with the current standards (e.g. as part of the safety reassessment of the plant) to determine whether the safe operation of the plant could be further enhanced by means of reasonably practicable safety improvements (see para. 1.3 of SSR-2/1 (Rev. 1) [1]).

1.10. The terms used in this Safety Guide are to be understood as defined and explained in the IAEA Safety Glossary [3].

STRUCTURE

1.11. Section 2 provides general recommendations for the design of fuel handling and storage systems for nuclear power plants to meet the requirements mainly established in sections 3 and 4 of SSR-2/1 (Rev. 1) [1]. Sections 3–6 provide specific recommendations to fulfil the fundamental safety functions in terms of the general design approach and to meet the requirements mainly established in sections 5 and 6 of SSR-2/1 (Rev. 1) [1]. Sections 3 and 4 provide specific recommendations for the safe design of fuel storage systems and fuel handling systems, respectively. Section 5 provides specific recommendations for the safe design of equipment used for inspection and repair of irradiated fuel, and for handling damaged fuel. Section 5 also provides specific recommendations for the safe design of handling and storage systems for irradiated core components. Section 6 provides guidance on the design of handling equipment for spent fuel casks in the spent fuel pool.

1.12. The Annex describes some operating aspects of the handling of spent fuel casks.

2. DESIGN OBJECTIVES AND DESIGN APPROACH

MANAGEMENT SYSTEM

2.1. The design of fuel handling and storage systems is required to be conducted in accordance with Requirements 1–3 of SSR-2/1 (Rev. 1) [1] and the requirements established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [4]. The recommendations provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [5], and GS-G-3.5, The Management System for Nuclear Installations [6], should also be taken into account.

FUNDAMENTAL SAFETY FUNCTIONS

2.2. In accordance with Requirement 4 of SSR-2/1 (Rev. 1) [1], the design should identify the fuel handling and storage structures, systems and components that are necessary to fulfil the following fundamental safety functions for all plant states:

(a) Maintaining subcriticality of the fuel;
(b) Removal of the decay heat from irradiated fuel;
(c) Confinement of radioactive material, shielding against radiation as well as limitation of accidental radioactive releases.

DESIGN APPROACH

Maintaining subcriticality of the fuel

2.3. Paragraphs 2.4–2.6 address the requirements in para. 6.66(a) of SSR-2/1 (Rev. 1) [1].

2.4. Fuel handling and storage systems are required to be designed to prevent criticality by maintaining specified subcriticality margins in all operational states and accident conditions.

2.5. The storage systems for authorized fuel[2] should be designed to prevent criticality preferably by the use of geometrically safe configurations.

2.6. The design of fuel storage systems should consider the use of physical means or physical processes to increase subcriticality margins in normal operation to avoid reaching criticality during postulated initiating events, including those postulated initiating events arising from the effects of internal hazards and external hazards.

Removal of the decay heat from irradiated fuel

2.7. In accordance with para. 6.67(a) of SSR-2/1 (Rev. 1) [1], fuel handling and storage systems are required to be designed to maintain adequate fuel cooling capabilities for irradiated fuel. As such, these systems should be designed to

[2] Authorized fuel refers to specific fuel type(s) licensed for use in fuel handling and storage systems.

ensure that the fuel cladding temperature limits and/or the coolant temperature limits, as defined for operational states and accident conditions, are not exceeded.

Confinement of radioactive material and limitation of radioactive releases

2.8. Paragraphs 2.9–2.11 provide recommendations on meeting Requirements 5 and 80 of SSR-2/1 (Rev. 1) [1].

2.9. Design provisions are required to prevent damage to the fuel (rods and assemblies) during handling (see para. 6.66(d) of SSR-2/1 (Rev. 1) [1]). There should also be design provisions to collect and filter radioactive material from the spent fuel storage in order to keep radioactive releases as low as reasonably achievable in operational states.

2.10. Ventilation systems are required to be implemented, as necessary, to reduce the concentrations of airborne radioactive material, and to prevent or reduce direct exposure and contamination in areas with radiation hazards (see Requirement 73 of SSR-2/1 (Rev. 1) [1]).

2.11. Design provisions should be provided to collect and filter radioactive material released and to prevent uncovering of irradiated fuel assemblies in the spent fuel storage in accident conditions.

Shielding against radiation

2.12. Paragraphs 2.13 and 2.14 provide recommendations on meeting Requirements 5 and 81 of SSR-2/1 (Rev. 1) [1].

2.13. Fuel handling equipment and fuel storage systems should include shielding as necessary to keep occupational doses as low as reasonably achievable in operational states.

2.14. Design provisions should be implemented as necessary to prevent a loss of shielding from irradiated fuel resulting in high radiation doses for workers in operational states and accident conditions (see also para. 2.11 of SSR-2/1 (Rev. 1) [1]).

Interfaces of safety with security and safeguards

2.15. To meet Requirement 8 of SSR-2/1 (Rev. 1) [1], items important to safety in relation to fuel handling and storage should be designed taking into account safety and nuclear security in an integrated manner in such a way that safety measures do not compromise nuclear security and nuclear security measures do not compromise safety. Nuclear security measures should be consistent with the objective and essential elements established in IAEA Nuclear Security Series No. 20, Objective and Essential Elements of a State's Nuclear Security Regime [7], and the recommendations provided in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) [8].

2.16. The design of fuel handling and storage systems should also facilitate the application and maintenance of IAEA safeguards, and the State system of accounting for, and control of, nuclear material.

Proven engineering practices

2.17. To meet Requirement 9 of SSR-2/1 (Rev. 1) [1], items important to safety in relation to fuel handling and storage should be of a design that has been proven either in equivalent applications based on operating experience or by the results of a relevant research programme. Alternatively, such items should conform to the design and design verification and validation processes stated in applicable codes and standards.

Safety assessment in design process

2.18. To meet Requirement 10 and para. 4.17 of SSR-2/1 (Rev. 1) [1], the safety assessment of fuel handling and storage systems is required to be performed as part of the design process, with iterations between design stages and safety analyses, and with increasing scope and level of detail as the design progresses. Recommendations on deterministic safety assessment are provided in IAEA Safety Standards Series No. SSG-2 (Rev. 1), Deterministic Safety Analysis for Nuclear Power Plants [9], and recommendations on probabilistic safety assessment are provided in IAEA Safety Standards Series Nos SSG-3, Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants [10], and SSG-4, Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants [11].

Other considerations

2.19. In addition to ensuring that fuel is stored safely, fuel handling and storage systems are also required to facilitate the following activities (see paras 6.66 and 6.67 of SSR-2/1 (Rev. 1) [1]):

(a) Inspection of the fuel (rods and assemblies);
(b) Maintenance, periodic inspection, calibration and testing of items important to safety;
(c) Identification of individual fuel assemblies;
(d) Arrangements to permit accounting for, and control of, nuclear fuel;
(e) Decontamination of areas, maintenance and future decommissioning.

2.20. To meet Requirement 12 of SSR-2/1 (Rev. 1) [1], design provisions should be introduced to minimize the potential for generating radioactive effluents and waste during normal operation.

2.21. The effects of irradiation should be considered in the design of structures, systems and components of fuel handling and storage systems.

3. DESIGN BASIS FOR STRUCTURES, SYSTEMS AND COMPONENTS OF FUEL STORAGE

GENERAL

3.1. In the context of this Safety Guide, items important to safety include the pool structure, pool liner, pool cooling systems, pool purification systems, make-up systems, gates and fuel storage racks.

3.2. Items important to safety are required to be designed in compliance with Requirement 80 of SSR-2/1 (Rev. 1) [1], with account taken of Requirements 14–28 of SSR-2/1 (Rev. 1) [1] relevant to:

(a) The protection of workers, the public and the environment from harmful effects of ionizing radiation in operational states and in accident conditions;
(b) Adequate reliability of the various systems;

(c) Prevention of high radiation fields on the site, and practical elimination of accident conditions that could lead to an early radioactive release or a large radioactive release.

3.3. To meet Requirement 14 of SSR-2/1 (Rev. 1) [1], the design basis of items important to safety should take into account the following:

(a) The safety function(s) to be performed by the items or to which the items contribute;
(b) The postulated initiating events the items have to withstand;
(c) The protection against the effects of internal hazards and external hazards;
(d) The safety classification;
(e) The design limits or acceptance criteria;
(f) The engineering design rules for the items;
(g) Recommended instrumentation and monitoring;
(h) Provisions against common cause failures;
(i) The environmental conditions considered in the qualification programme;
(j) The selection of materials.

3.4. The design should define the necessary provisions and devices to facilitate the use of non-permanent equipment for the re-establishment of safe conditions in the fuel storage in the event of multiple failures that are not accounted for in the design basis. This includes the provision of flanges and sockets for the use of mobile equipment.

DEFENCE IN DEPTH

3.5. Paragraphs 3.6–3.8 provide recommendations on meeting Requirement 7 of SSR-2/1 (Rev. 1) [1].

3.6. The design of spent fuel storage systems should include multiple means to remove decay heat from irradiated fuel and to maintain subcriticality margins in all the plant states considered in the design.

3.7. The application of the concepts of redundancy, diversity and functional independence should be defined taking into account para. 3.8. The combined application of redundancy, diversity and independence among the various cooling means should be adequate to demonstrate that the coolant temperature limits defined for operational states and for accident conditions are not exceeded and that the uncovering of the fuel assemblies is prevented with a high level of confidence.

3.8. The potential for common cause failures of the means of decay heat removal should be identified and the consequences of such failures should be assessed. In cases that might result in the uncovering of the assemblies or an interruption to the removal of decay heat, the identified vulnerabilities should be removed to the extent possible by the provision of diverse and redundant means.

SAFETY FUNCTIONS

3.9. The safety functions performed by the fuel handling and storage systems and the contribution of each major structure and component in the fulfilment of these functions should be described in a level of detail that is sufficient to enable the design bases of the structures, systems and components to be defined.

POSTULATED INITIATING EVENTS

3.10. Paragraphs 3.11–3.13 provide recommendations on meeting Requirement 16 of SSR-2/1 (Rev. 1) [1].

3.11. For spent fuel storage, an adequate coolant inventory in the fuel storage area is essential to the fundamental safety functions of decay heat removal and radiation protection, and can contribute to maintaining subcriticality margins. Therefore, the potential for a significant loss of coolant inventory should be a major consideration in the identification of postulated initiating events.

3.12. Postulated initiating events relevant to the design of fuel storage systems should include those events that potentially lead to a reduction in subcriticality margin, a reduction in decay heat removal capability, a significant release of radioactive material or a significant direct radiation exposure of operating personnel. Postulated initiating events are caused by equipment failures, operator errors, internal hazards or external hazards. Typical examples of postulated initiating events are provided in paras 3.50 and 3.52.

3.13. Bounding cases associated with the postulated initiating events should be determined to define the necessary performance capabilities of the equipment designed to mitigate their consequences (see para. 5.9 of SSR-2/1 (Rev. 1) [1]).

INTERNAL HAZARDS

3.14. Paragraphs 3.15–3.33 provide recommendations on meeting Requirement 17 of SSR-2/1 (Rev. 1) [1] in relation to internal hazards.

3.15. Items important to safety are required to be designed to withstand loads resulting from, or to be protected against the effects of, internal hazards (see para. 5.15A of SSR-2/1 (Rev. 1) [1]). The design should also consider the consequences of the failure of unprotected equipment.

3.16. The redundant elements of the fuel handling and storage systems should be segregated to the extent possible, or else should be adequately separated, and protected as necessary to prevent the loss of the safety function performed by the systems (i.e. to prevent common cause failures initiated by the effects of internal hazards).

3.17. The effects of a single hazard should not result in the failure of the entire cooling capability of spent fuel storage systems.

3.18. The storage building should be designed to withstand the loadings generated by hazards occurring within the plant site (e.g. explosions, internally generated missiles).

3.19. The design methods and construction codes used should provide adequate margins to avoid cliff edge effects in the event of a minor increase in the severity of an internal hazard above the design basis.

3.20. The recommendations provided in IAEA Safety Standards Series No. SSG-64, Protection against Internal Hazards in the Design of Nuclear Power Plants [12] should be considered in order to identify the relevant hazards and develop appropriate methods of protecting equipment from these hazards.

3.21. Typical examples of internal hazards that influence the design of fuel handling and storage systems are provided in paras 3.22–3.33.

Heavy load drop

3.22. The potential for falling heavy loads to damage stored fuel or otherwise impact the fulfilment of the fundamental safety functions is required to be considered in the design (see para. 6.67(d) of SSR-2/1 (Rev. 1) [1]). Falling objects are primarily the result of component failures and errors by operating personnel during fuel handling.

3.23. Owing to the frequency of fuel handling, the dropping of a fuel assembly in any area traversed during the handling should be considered. The dropping of loads in the fuel storage area could also occur during the movement of watertight gates, the transfer of tools, and the installation or removal of fuel storage racks.

3.24. Very heavy objects associated with refuelling operations (e.g. reactor vessel head, activated internal structures of the reactor) and fuel transfer or storage cask loading operations should be excluded from consideration as hazards in the fuel storage area through prevention, with a high level of confidence, by means of the layout of the refuelling, fuel storage and cask loading areas, and by careful design of the handling equipment.

3.25. The design and layout of fuel handling and storage systems should prevent the movement of heavy objects over the fuel storage areas through spatial separation, and should prevent indirect effects through structural independence of the fuel storage area and the construction of weirs or other structures to prevent a substantial loss of coolant inventory in the event of heavy load drops that damage structures in nearby areas.

Internal flooding in dry storage areas for fresh fuel

3.26. The design and layout of dry storage areas for fresh fuel should provide protection against internal flooding by means of, for example, flood barriers, routing of water piping through areas isolated from the fuel storage and adequate drains, in order to maintain subcriticality margins.

Pipe breaks

3.27. Equipment that performs a fundamental safety function should be protected against the effect of high energy and moderate energy pipe breaks.

3.28. The substantial loss of coolant inventory from spent fuel storage systems due to a pipe break should be avoided by ensuring that all liner penetrations in the fuel storage area are above the elevation necessary for adequate shielding in the spent fuel pool area (see para. 6.68 of SSR-2/1 (Rev. 1) [1]).

Fires

3.29. The recommendations provided in SSG-64 [12] should be implemented to reduce the probability of a fire being started, to limit the propagation of the fire, to protect items important to safety and to prevent the loss of the fundamental safety functions. Paragraphs 3.30–3.32 provide recommendations specific to fuel storage.

3.30. For spent fuel storage, the different cooling means and each redundant division of a cooling system should be located in individual fire compartments, or at least each of these should be in an individual fire cell if implementing individual fire compartments is not achievable.

3.31. To be protected from fire, dry storage areas for fresh fuel should be located inside a fire compartment.

3.32. The effects of firefighting agents on the subcriticality of fresh fuel in dry storage should be considered. For both fresh fuel and irradiated fuel in wet storage, the effects of firefighting agents on the subcriticality of the system should also be considered (e.g. when unborated water makes its way into borated water).

Explosions

3.33. If hydrogen generation is considered as a hazard, specific design provisions should be implemented to prevent hydrogen generation or to limit hydrogen concentration (e.g. ensuring material compatibility with spent fuel pool coolant chemistry or providing ventilation). These provisions should ensure that the hydrogen concentration is kept at a safe level below the lower flammability limits, including in locations where higher hydrogen concentration might exist.

EXTERNAL HAZARDS

3.34. Paragraphs 3.35–3.43 provide recommendations on meeting Requirement 17 of SSR-2/1 (Rev. 1) [1] in relation to external hazards.

3.35. The recommendations provided in IAEA Safety Standards Series No. SSG-68, Design of Nuclear Installations against External Events Excluding Earthquakes [13], should be considered in order to understand the general concept of identifying relevant external hazards and protecting structures, systems and components against the effects of these hazards.

3.36. For fuel storage, items important to safety designed to accomplish fundamental safety functions are required to be protected against, or designed to withstand the effects of, the selected external hazards (see para. 5.15A of SSR-2/1 (Rev. 1) [1]).

3.37. The protection of fuel storage systems against the effect of external hazards should primarily rely on an adequate layout and design of the buildings at the site.

3.38. For each hazard or likely combinations of hazards, the structures, systems and components whose operability and/or integrity needs to be maintained during or after the hazard should be identified and specified. Where the protection provided by the layout and design of the buildings is not sufficient, structures, systems and components should be designed to withstand the loadings generated by the hazard and by likely combinations of hazards.

3.39. With regard to fuel storage, items important to safety should be assigned the appropriate seismic categories in accordance with the recommendations provided in IAEA Safety Standards Series No. SSG-67, Seismic Design for Nuclear Power Plants [14]. The structures, systems and components necessary for the fulfilment of the safety functions should be designed to withstand SL-2 seismic loads, and provision should be made to protect them against the effects of such loads on other equipment.

3.40. The seismic design specifications for items important to safety should be established on the basis of the consequences of potential damage to stored fuel assemblies, the release of radioactive material in the building and the need to operate the storage systems during and after an earthquake. The design of the spent fuel storage for seismic qualification should take into account the potential for a decrease of the coolant inventory due to sloshing and for a reduction of subcriticality margins due to the potential displacement of solid neutron absorbers.

3.41. For spent fuel storage, in the event of external hazards, short term actions necessary to maintain a sufficient coolant inventory and an adequate cooling of the fuel should rely on on-site equipment. Only long term actions should rely on off-site equipment or the availability of off-site services.

3.42. The methods of design, and the construction codes and standards used should provide adequate margins to prevent cliff edge effects in the event of an increase in the severity of the external hazards.

3.43. It should be ensured that the integrity of the structures, and the operability of systems and components, would be preserved in case of natural hazards causing loads that exceed those determined from the hazard evaluation at the site. With regard to fuel storage, criticality and high radiation doses should be prevented, and irradiated fuel cooling capability should be preserved.

PLANT CONDITIONS TO BE TAKEN INTO ACCOUNT IN DESIGN

Fuel storage capacity

3.44. The spent fuel storage capacity should be designed in accordance with a fuel management policy with a specified design capacity and specific positions for stored fuel assemblies. Adequate capacity for spent fuel storage should be provided to allow sufficient time for radioactive decay and for removal of residual heat before the spent fuel is removed from the spent fuel pool. The maximum storage capacity should consider the availability of licensed away-from-reactor storage facilities for spent fuel and the minimum time necessary for radioactive decay and for cooling before transfer. At a minimum, the storage capacity should allow for storage of all expected discharged fuel assemblies (in accordance with the fuel management policy) plus additional storage locations for unloading one full core. For mixed oxide fuel, the higher residual heat values that might further delay the transfer of the spent fuel into storage casks should be taken into account.

Normal operation

3.45. During normal operation, the fundamental safety functions should be accomplished without exceeding the limits and bounding conditions established for normal operation with regard to subcriticality margin, coolant temperature and occupational exposures (including radiation levels and airborne activity levels in the workplace).

3.46. Decay heat should be removed by a dedicated cooling system designed to maintain the coolant temperature below the maximum temperature specified for normal operation.

3.47. In the design of storage systems for spent fuel, adequate means should be implemented and available for:

(a) Maintaining coolant activity and coolant chemistry within the specifications established for normal operation;

(b) Compensating for the loss of coolant by evaporation;
(c) Collecting radioactive gases potentially leaking from defective fuel rods;
(d) Maintaining appropriate clarity of the coolant for fuel handling operations;
(e) Monitoring and controlling coolant temperature and coolant level;
(f) Monitoring and controlling airborne activity.

3.48. Ventilation and air conditioning for the spent fuel storage system should be designed in accordance with para. 6.48 of SSR-2/1 (Rev. 1) [1]. Recommendations for the design of ventilation air conditioning systems are provided in IAEA Safety Standards Series No. SSG-62, Design of Auxiliary Systems and Supporting Systems for Nuclear Power Plants [15].

Anticipated operational occurrences

3.49. Anticipated operational occurrences should be specified to define the design provisions necessary to maintain subcriticality margins, cooling conditions and the coolant inventory within the limits established for anticipated operational occurrences.

3.50. Typical examples[3] of postulated initiating events that can result in anticipated operational occurrences, based on their frequency of occurrence and radiological consequences, include the following:

(a) Loss of off-site power;
(b) Loss of coolant (small leaks) in the cooling and filtration and/or purification system, or through the seals of gates;
(c) Loss of cooling water flow or (for pressurized water reactors) dilution of soluble neutron absorbers;
(d) Malfunctioning of a fuel cooling system during normal operation;
(e) Abnormal fuel assembly configurations involving a single misplaced fuel assembly or a dropped fuel assembly (without cladding damage) in the fuel storage array.

Accident conditions

3.51. Credible equipment failures that cause conditions more severe than anticipated operational occurrences (i.e. with regard to the fundamental safety functions stated in para. 2.2) should be postulated.

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[3] Examples are design dependent and might not be taken into account in certain Member States.

3.52. Single equipment failures and multiple equipment failures should be considered in order to define design basis accident conditions and design extension conditions, respectively. Typical examples[4] of such failures to be considered include the following:

(a) Design basis accidents:
    (i) Significant loss of coolant (e.g. breaks of piping connected to the spent fuel pool);
    (ii) Failure of the cooling system used in normal operation;
    (iii) Abnormal fuel assembly configurations (e.g. a fuel assembly not placed in a design storage location and a dropped irradiated fuel assembly with cladding damage);
    (iv) A significant change of moderation conditions in fuel storage (e.g. large dilution of soluble neutron absorber (pressurized water reactor only) in the wet storage area or flooding of the dry storage area).
(b) Design extension conditions:
    (i) Multiple failures leading to the loss of the forced cooling system for a long period;
    (ii) Combinations of failures selected on the basis of probabilistic risk assessments (e.g. a combination of anticipated operational occurrences or postulated accidents with a common cause failure affecting the system designed for mitigating the event of concern).

DESIGN LIMITS

3.53. Paragraphs 3.54–3.58 provide recommendations on meeting Requirements 15 and 28 of SSR-2/1 (Rev. 1) [1].

3.54. The performance of structures, systems and components for spent fuel storage should meet the acceptance criteria established for different operational states and accident conditions.

3.55. Stresses caused by load combinations should not exceed the stress limits defined by the design codes for the structures, systems and components.

[4] Examples are design dependent and might not be taken into account in certain Member States.

3.56. Criticality is required to be prevented in all operational states and accident conditions with specified margins (see para. 6.66(a) of SSR-2/1 (Rev. 1) [1]). Examples of good practices[5] include the following:

(a) For dry storage of fresh fuel, the effective multiplication factor calculated for optimum moderation conditions should not exceed values specified in national regulations (e.g. 0.95–0.98, including uncertainties).
(b) For wet storage of irradiated fuel, the effective multiplication factor calculated should not exceed 0.95 in normal operation and should not exceed values specified in national regulations (e.g. 0.95–0.98, including uncertainties) in anticipated operational occurrences and in accident conditions.

3.57. For wet storage of irradiated fuel, an adequate coolant inventory should be maintained over the top of the irradiated fuel assemblies for shielding in all operational states and accident conditions, as follows:

(a) For wet storage of irradiated fuel, the water level in the pool should be sufficient to provide radiation shielding for operating personnel during fuel handling operations to ensure that doses to such personnel will be maintained below the dose limits and will be kept as low as reasonably achievable in normal operation and in anticipated operational occurrences.
(b) In accident conditions, a substantial coolant inventory should be maintained to provide radiation shielding.

3.58. For wet storage of irradiated fuel, decay heat removal should be adequate to maintain the spent fuel pool temperature at acceptable levels for operating personnel and for the normal operation purification system for all conditions of normal operation, including high decay heat loads associated with refuelling. For anticipated operational occurrences, the decay heat removal capability should be promptly restored to return the pool temperature to normal operating conditions without reaching boiling conditions. In accident conditions, adequate removal of heat should be maintained by relying on inherent safety features, on the operation of active or passive systems, or on a combination of safety features and active and passive systems, as follows:

(a) Maintaining forced cooling in design basis accidents and in design extension conditions; or

[5] Examples are design dependent and might not be taken into account in certain Member States.

(b) Maintaining forced cooling in design basis accidents and relying on the venting of evaporated coolant to the atmosphere for heat removal, supplemented by gravity driven flow of make-up water to compensate for the loss of coolant inventory due to evaporation in design extension conditions.

RELIABILITY

3.59. Paragraphs 3.60–3.80 provide recommendations on meeting Requirements 18, 21–26, 29, 30 and 80 of SSR-2/1 (Rev. 1) [1].

3.60. To meet the requirements established in para. 5.37 of SSR-2/1 (Rev. 1) [1], the design of items important to the safety of spent fuel storage is required to ensure that these items can withstand all conditions specified in their design bases with sufficient reliability and effectiveness.

3.61. As stated in para. 6.68 of SSR-2/1 (Rev. 1) [1], the design for spent fuel storage systems is required to be such that “the possibility of conditions arising that could lead to an early radioactive release or a large radioactive release is ‘practically eliminated’...and so as to avoid high radiation fields on the site.”

3.62. The reliability of the different means designed to operate in different plant states should be commensurate with the safety importance of the function to be accomplished.

3.63. Different factors influence reliability and each of these factors should be considered in order to achieve adequate reliability of the different systems necessary to remove decay heat from spent fuel storage and to maintain an adequate coolant inventory in the pool. These factors include:

(a) Safety classification and the associated engineering rules for design and manufacturing of individual structures, systems and components;
(b) Design criteria relevant for the systems (number of redundant trains, seismic qualification, qualification relating to harsh environmental conditions, power supplies);
(c) Vulnerabilities for common cause failures and related design provisions (e.g. by means of diversity, separation and independence);
(d) Layout provisions to protect systems from the effects of internal hazards and external hazards;
(e) Design provisions for monitoring, inspection, testing and maintenance.

3.64. For normal operation, anticipated operational occurrences and accident conditions, the heat removal means should be designed with account taken of the maximum heat loads and the maximum heat sink temperature.

3.65. Methods to ensure the robust design of fuel storage systems should be applied in order to meet Requirement 18 of SSR-2/1 (Rev. 1) [1]. For all safety classes identified, corresponding engineering design rules should be specified and applied. These include:

(a) Use of appropriate codes and standards;
(b) Proven engineering practices;
(c) Conservative safety margins;
(d) Qualification.

Reliability for operational states

3.66. Gates separating spent fuel pools from other pools or compartments should be watertight in normal operation and anticipated operational occurrences.

3.67. Provisions should be implemented to detect, locate, isolate and collect any leakage of water through the metallic liners of the pool. Means should be in place for repairing small leakages through the metallic liners.

3.68. The cooling system operated in normal operation should be designed to maintain the coolant temperature below the maximum temperature specified for normal operation even when components of the system are unavailable due to maintenance.

3.69. The cooling system should be designed to maintain the coolant temperature below the maximum temperature specified for anticipated operational occurrences in the event of a loss of off-site power.

Reliability for accident conditions

3.70. The system(s) necessary to remove decay heat in design basis accidents should be designed to meet the single failure criterion.

3.71. The forced cooling system necessary to remove decay heat in design basis accidents should be provided with an emergency power supply.

3.72. A single equipment failure or piping break in the forced cooling system should not lead to the total loss of forced cooling.

3.73. Means should be implemented (e.g. isolation valves, anti-siphoning devices) to minimize the loss of coolant in the event of a pipe break.

3.74. The system necessary to remove decay heat in accident conditions should be designed so that it can be restarted in conditions in which the subcooling of the pool water is lost.

3.75. Water storage pools should not be designed with penetrations below the minimum water level necessary for the shielding of stored irradiated fuel in accident conditions.

3.76. The volume of the spent fuel pool should be adequate to ensure that, in the event of a loss of forced cooling, a sufficient period of time is available to allow for implementation of corrective measures before the water reaches the coolant temperature limits.

3.77. Design layout provisions should be implemented to prevent the top of the spent fuel assemblies from becoming uncovered and to maintain sufficient radiation shielding in the event of inadvertent or accidental leakage through a gate between the spent fuel pool and a drained fuel handling compartment.

3.78. The spent fuel storage racks should be designed to maintain an adequate heat transfer from each irradiated fuel assembly through natural convective flow to prevent nucleate boiling within the fuel assembly.

3.79. Design provisions should be implemented to compensate for the loss of coolant by evaporation and for potential leakage associated with postulated accidents. Such provision includes a permanently installed system that provides emergency make-up water to restore the coolant inventory

3.80. Additional provisions should be implemented to facilitate the use of non-permanent equipment or other permanently installed equipment to recover the coolant inventory and decay heat removal capability (see para. 6.68(c) of SSR-2/1 (Rev. 1) [1]). Such provisions should be in an area where access can be ensured.

Connecting devices should be provided outside the spent fuel storage area. Typical provisions include the following:

(a) Connection to other permanently installed systems, for example the service water system and the fire water system;
(b) Installation of piping and fittings to allow connection of a cooling system or the delivery of make-up water using portable equipment in areas away from the spent fuel pool;
(c) Provisions for ventilation of the spent fuel pool area to remove decay heat and steam;
(d) Provisions to recover forced cooling of the spent fuel pool in the event of an extended loss of AC power (i.e. station blackout);
(e) Means for the temporary repair of small leaks through the metallic liners of the pool.

STRUCTURAL INTEGRITY

3.81. The structural integrity and operability of structures and components designed to fulfil the fundamental safety functions should be maintained throughout their lifetime in all operational states and accident conditions in which they are designed to operate. The design should take account of relevant loading conditions (e.g. stress, temperature, corrosive environment, radiation levels), and should consider creep, fatigue, thermal stresses, corrosion, changes in material properties with time (e.g. concrete shrinkage) and the potential for degradation of reinforcing material.

3.82. Loads and load combinations considered in the design should be identified, justified and documented. Typical examples of design load combinations for strength analyses and evaluation of stress analysis results are described in paras 3.83–3.87.

3.83. Design loads that should be considered in the design of storage racks for fresh fuel include the following:

(a) Static loads;
(b) Uplift forces on the racks due to the fuel handling machine (with an assumption that the forces are applied to a postulated stuck fuel assembly);
(c) SL-2 seismic loads.

3.84. Design loads that should be considered in the design of storage racks for spent fuel include the following:

(a) The loads listed in para. 3.83;
(b) Dynamic loads resulting from the dropping of a fuel assembly;
(c) Thermal loads.

3.85. Design loads that should be considered in the design of the storage structure for spent fuel include the following:

(a) SL-2 seismic loads and associated hydrodynamic loads due to water movement in the storage area;
(b) Dynamic loads resulting from the dropping of a spent fuel cask;
(c) Loads from thermal effects resulting from an extended loss of cooling event;
(d) Static loads.

3.86. Methods for combining individual loads should be established in accordance with applicable codes and standards.

3.87. The allowable stresses for given loading conditions should comply with limits specified in applicable proven codes and standards. If there are no such codes or standards, justification should be provided for the allowable stress levels selected.

SAFETY CLASSIFICATION

3.88. Paragraphs 3.89–3.93 provide recommendations on meeting Requirement 22 of SSR-2/1 (Rev. 1) [1]. Recommendations on safety classification are provided in IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants [16].

3.89. For the purposes of safety classification, the consequences of the failure of the item in terms of the failure to perform the safety function, the radiation exposure of workers and the level of the radioactive release should be considered.

3.90. The safety classification should be established in a consistent manner such that all systems necessary (including the supporting systems) for the fulfilment of the same function in a specific plant state are assigned to the same class, or else a justification for assigning a different class should be provided.

3.91. In accordance with Requirement 9 of SSR-2/1 (Rev. 1) [1], pressure retaining equipment should be designed and manufactured in accordance with requirements established by national or international codes appropriate to their safety classification and the applicability of the selected design standard should be justified (e.g. see Refs [17–19]). The engineering design and manufacturing rules applicable to each individual component should be selected with due account taken of the two effects resulting from its failure (function not fulfilled and radioactive release).

3.92. Specific structures or components should be designed and manufactured in accordance with requirements established by national or international codes appropriate to their safety class; the applicability of the selected design standard should be justified.

3.93. In accordance with the recommendations provided in SSG-30 [16]:

(a) Structures that ensure subcriticality margins should be assigned to safety class 1;
(b) Systems designed not to exceed the design limits applicable to design basis accidents should be assigned to safety class 2, or to safety class 1 if they are needed in the short term;
(c) Systems implemented as a backup of the system designated for design basis accidents should be assigned to safety class 3, or to safety class 2 if they are needed in the short term;
(d) Systems for heat removal in normal operation should be assigned to safety class 3;
(e) Systems designed for operational states and whose failure would not lead to radiological consequences exceeding the limit specified for operational states need not be safety classified.

ENVIRONMENTAL QUALIFICATION

3.94. Paragraphs 3.95–3.100 provide recommendations on meeting Requirement 30 of SSR-2/1 (Rev. 1) [1].

3.95. Structures, systems and components should be qualified to perform their intended functions in the entire range of environmental conditions that might prevail before or during their operation until their mission time is completed (see Requirement 30 of SSR-2/1 (Rev. 1) [1]), or should otherwise be adequately protected from those environmental conditions.

3.96. The relevant environmental and seismic conditions that might prevail before, during and following an accident, the ageing of structures, systems and components throughout the lifetime of the plant, synergistic effects and margins should all be taken into consideration in the environmental qualification. Further recommendations are provided in SSG-67 [14] and in IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [20].

3.97. Environmental qualification should include the consideration of such factors as temperature, pressure, humidity, radiation levels, radioactive aerosols, vibration, water spray, steam, flooding, electromagnetic influence, contact with chemical agents and combinations of these factors.

3.98. Environmental qualification should be carried out by means of testing, by analysis (including the use of engineering expertise) or by a combination of both (see also paras 5.49 and 5.50 of SSR-2/1 (Rev. 1) [1]).

3.99. For components subject to the effects of ageing by various mechanisms, a design life, a programme of inspection and a replacement frequency (if appropriate) should be established. In the qualification of such components, samples should be subjected to artificial ageing experiments to simulate the end of their design lives before being tested under design basis accident conditions.

3.100. Qualification data and results should be documented and kept available as part of the design documentation.

PREVENTION OF CRITICALITY

3.101. When a subcritical margin cannot be maintained by control of geometry, additional means such as fixed neutron absorbers should be applied. If fixed neutron absorbers are used, it should be ensured by proper design and fabrication that the absorbers will not become separated or displaced in operational states or in accident conditions, including during or after an earthquake.

3.102. When soluble absorbers are used to meet the design limit for accident conditions, it should be demonstrated that pure water will not cause criticality in all modes of normal operation.

3.103. Any geometric deformations of the fuel or storage equipment that could be caused by any postulated initiating events should be taken into account in the design provisions for the prevention of criticality. Consideration should also be given to routine fuel movements that could bring the fuel being moved into proximity with stored fuel or in which fuel could be dropped and fall onto, or next to, stored fuel.

3.104. The lattice of the spent fuel storage racks should be designed to prevent any reduction of subcriticality margins due to, for example, the entrapment of air or steam during fuel handling or storage.

3.105. Provision should be made in the design of fuel storage racks to prevent placement of fuel assemblies into inappropriate positions.

3.106. In determining subcriticality, a conservatively calculated value of the effective multiplication factor k_{eff} or, alternatively, the infinite multiplication factor k_{∞} should be used. Recommendations on criticality safety are provided in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [21]. The following recommendations apply in respect of the design of fuel handling and storage systems:

(a) An adequate subcriticality margin in all credible conditions should be demonstrated, with account taken of all the uncertainties in the calculation codes and experimental data.
(b) If the enrichment is variable within a fuel assembly, exact modelling should be used or a conservative uniform enrichment of the fuel assembly should be assumed.
(c) If the enrichments of the fuel assemblies differ, the design of the storage racks for fresh fuel should generally be based on the enrichment value corresponding to that of the fuel assembly with the highest enrichment or the most reactive fuel assembly.
(d) All spent fuel assemblies should be assumed to have a burnup and enrichment that result in maximal reactivity, unless credit for burnup is assumed on the basis of a justification that includes appropriate measurements confirming the calculated values for fissile content or depletion level before storage of the fuel.
(e) Where the fuel design is variable and/or there are uncertainties in any data relating to the fuel (in terms of design, geometrical and material specifications, manufacturing tolerances and nuclear data), conservative values should be used in all subcriticality calculations. If necessary, a sensitivity analysis should be performed.
(f) The inventory of the fuel storage racks should be assumed to be at the maximum capacity of the design.

(g) Credit should not be claimed for neutron absorbing parts or components of fuel storage racks for normal operations unless they are permanently installed.
(h) The fuel storage racks should be designed so that lateral, axial and bending loads leading to unacceptable dimensional changes of the fuel are prevented. Any geometric deformations of the fuel and the storage racks that could be caused by any postulated initiating event or by the design basis earthquake should be taken into account in the criticality assessment.
(i) Appropriate conservative assumptions for moderation should be made.
(j) Consideration should be given to the effects of neutron reflection, by taking into account the exact design of the fuel storage racks including materials, dimensions and spacing between the fuel storage racks and between the fuel storage racks and the structures near the racks (e.g. floors and walls).
(k) Assumptions with regard to neutronic decoupling for different storage zones, if applicable, should be substantiated by appropriate calculations.
(l) Allowance for the presence of burnable absorbers that are integral parts of fuel assemblies should be made only on the basis of a justification that is acceptable to the regulatory body and that includes consideration of the possible reduction of subcriticality margins due to burnout of a burnable absorber.

RADIATION PROTECTION

3.107. The design of a spent fuel storage facility should provide for radiation protection of workers, the public and the environment in accordance with the requirements of national legislation and the requirements established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [22]. Further recommendations are provided in IAEA Safety Standards Series No. NS-G-1.13, Radiation Protection Aspects of Design for Nuclear Power Plants [23].

3.108. In accordance with para. 6.48 and Requirement 81 of SSR-2/1 (Rev. 1) [1], suitable ventilation systems and shielding should be implemented to maintain the concentrations of airborne radioactive material and the direct radiation exposure of workers as low as reasonably achievable in operational states.

3.109. Suitable confinement and filtration systems should be implemented to minimize the radiological consequences to the public and the environment and to ensure that these consequences are below the limits defined for operational states and accident conditions.

3.110. For the design of shielding, bounding cases should be considered for initial fuel composition, burnup and cooling times for gamma and neutron radiation, the inventory of the irradiated fuel at the maximum design capacity of the spent fuel storage facility, the effects of axial burnup on gamma and neutron sources, the mobility of activated crud and the activation of non-fuel components.

3.111. Penetrations through shielding barriers (e.g. penetrations associated with cooling systems or penetrations provided for loading and unloading) should be designed to avoid localized high gamma and neutron radiation fields, either directly through the penetration or due to radiation streaming.

3.112. Fresh fuel containing fissionable material recovered by reprocessing emits a significant amount of radiation. In dry storage, additional shielding should be provided to limit the exposure of operating personnel from the handling and storage of such fuel.

MATERIALS

3.113. Structural materials and welding methods should be selected on the basis of accepted design codes and standards. Consideration should be given to the potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields. In addition, potential material degradation due to thermal effects should also be considered.

3.114. The material used for the pool liner and other structural materials in contact with the coolant (e.g. racks) should have a low sensitivity to corrosion phenomena taking into account coolant chemistry.

3.115. Materials in direct contact with fuel should be compatible with the materials of the fuel assemblies, and should be such as to minimize chemical and galvanic reactions that might degrade the integrity of the irradiated fuel during its storage. Materials in direct contact with irradiated fuel should not contaminate the irradiated fuel with substances that might significantly degrade the integrity of the irradiated fuel during its storage.

3.116. Materials used in the construction of fuel storage systems should allow easy decontamination of surfaces.

3.117. The compatibility of decontamination materials with the operating environment should be considered.

3.118. Materials used in the construction of fuel storage systems should comply with the recommendations in paras 3.29–3.32 with regard to protection against fires.

3.119. For storage racks that use fixed solid neutron absorbers, it should be possible throughout the operating lifetime of the storage racks to demonstrate that:

(a) The fixed solid neutron absorbers have not lost their effectiveness;
(b) The fixed solid neutron absorbers are chemically compatible with the other rack components and are chemically stable when immersed in water.

MONITORING

3.120. Paragraphs 3.121–3.128 provide recommendations on meeting para. 6.68A and Requirement 82 of SSR-2/1 (Rev. 1) [1].

3.121. Adequate and qualified (as necessary) instrumentation should be implemented for monitoring water temperature in the irradiated fuel storage for operational states and for accident conditions (see para. 6.68A(a) of SSR-2/1 (Rev. 1) [1]).

3.122. Adequate and qualified instrumentation should be implemented for monitoring the water level in the spent fuel storage in operational states and in accident conditions (see para. 6.68A(b) of SSR-2/1 (Rev. 1) [1]). Reliable instrumentation for monitoring the water level over a wide range should be implemented for monitoring under accident conditions.

3.123. Adequate and qualified instrumentation should be implemented for monitoring the activity in air in fuel storage and fuel handling areas for operational states and for relevant accident conditions (see para. 6.68A(c) of SSR-2/1 (Rev. 1) [1]).

3.124. Adequate and qualified instrumentation should be implemented for monitoring the activity in water in the irradiated fuel storage for operational states and for relevant accident conditions (see para. 6.68A(c) of SSR-2/1 (Rev. 1) [1]).

3.125. Adequate means should be implemented for monitoring chemical parameters in the spent fuel pool in operational states (see para. 6.68A(d) of SSR-2/1 (Rev. 1) [1]). This should include monitoring the concentration of soluble absorbers, as appropriate.

3.126. Instrumentation necessary for monitoring key parameters that will be used in accident management should be redundant.

3.127. Areas in which irradiated fuel is handled or stored should be provided with suitable radiation monitoring equipment and alarms for the protection of operating personnel. This should include an adequate number of radiation monitors to ensure the protection of personnel operating fuel handling machines. Provision should be made for continuous air monitoring in any area in which airborne radioactive material might be released during the handling of irradiated fuel. More detailed recommendations are provided in IAEA Safety Standards Series No. RS-G-1.8, Environmental and Source Monitoring for Purposes of Radiation Protection [24].

3.128. The design of fuel storage facilities should consider and facilitate the use of remote and robotic technology for monitoring and measurement of potentially very high dose rates, particularly in the event of an accident.

DESIGN OF WATER PURIFICATION SYSTEMS FOR THE SPENT FUEL POOL

3.129. Limits on concentrations of radionuclides in spent fuel pool water should be specified. Limits should also be established for water quality and for levels of radionuclides in the air.

3.130. Systems for purification of the spent fuel pool water should be designed to ensure that:

(a) Radioactive, ionic and solid impurities arising from activation products, damaged fuel and other sources can be removed from the water so as to ensure that the radiation dose rate due to the water itself can be maintained within the specified limits.
(b) The limits relating to the chemistry of the pool water (e.g. boron concentration, content of chloride, sulphate and fluoride as appropriate, pH value and conductivity) that are defined for normal operation in relation to maintaining subcriticality and minimizing corrosion can be complied with.
(c) The clarity of water can be maintained at an acceptable level so that fuel handling operations in water can be monitored.
(d) The capacity of the purification system is sufficient to purify the water volume in the spent fuel pool within a specified period of time.
(e) Provision is made for the control of microbial growth, as appropriate.

3.131. Systems for purification of spent fuel pool water should be designed to be able to remove impurities and suspended particles from the surface of the pool water.

3.132. The design of systems for the purification of spent fuel pool water should provide means for the local removal of pool water and for routing to the purification system or to local purification equipment, in the event of operations in which the release of radioactive material might increase or the suspension of particles might occur, for example, during fuel reconstitution.

3.133. The design of systems for the purification of spent fuel pool water should include measures for preventing the spread of airborne radionuclides, including halogens, from the surface of the pool (e.g. by positioning the ventilation and air conditioning suction inlets near the pool surface).

3.134. The design of the systems for the purification of spent fuel pool water should provide measures for preventing the unacceptable buildup of contamination in fuel storage areas and for facilitating the reduction of contamination to acceptable levels if buildup does occur. Piping should be designed with a minimum of flanges and other features (such as traps or loops) in which radioactive material might accumulate.

3.135. The maximal coolant temperature in normal operation should not exceed the maximum permissible temperature of the purification equipment (e.g. ion exchanger).

ILLUMINATION EQUIPMENT

3.136. Paragraphs 3.137–3.140 provide recommendations on meeting Requirement 75 of SSR-2/1 (Rev. 1) [1].

3.137. Operational areas for irradiated fuel handling and storage, including the pool area, should be provided with the necessary illumination equipment (i.e. underwater lighting near work areas and a means for the replacement of underwater lamps) to permit the satisfactory handling and visual inspection and identification of fuel assemblies.

3.138. Materials used in underwater lighting should be appropriate for the environmental conditions and in particular should not undergo unacceptable corrosion or cause any unacceptable contamination of the water.

3.139. Resistance to impact and thermal shocks should be provided to the extent possible.

3.140. Lighting technologies with a high temperature spectrum to maximize the range of transmission through water should be selected.

4. DESIGN BASIS FOR EQUIPMENT AND COMPONENTS OF FUEL HANDLING SYSTEMS

4.1. Fuel handling systems are mainly used to unload and reload the reactor core. Fuel handling systems used in light water reactors include the following:

(a) A refuelling machine to handle the new or irradiated fuel assemblies for loading and unloading the core and to move the assemblies between the core and either the fuel transfer system (for pressurized water reactors) or directly to the storage location (for boiling water reactors);
(b) A system to transfer fuel assemblies between the reactor pool and the spent fuel pool through the fuel transfer channel (for typical pressurized water reactors);
(c) Systems to move and locate fuel assemblies in fuel storage areas (e.g. auxiliary crane or hoist, fresh fuel elevator, fuel handling machine);
(d) Fuel handling tools (e.g. unlatching tools for the control rod drive shaft, fresh fuel assembly handling tools, spent fuel assembly handling tools).

4.2. Fuel handling systems used in pressurized heavy water reactors (channel type) include the following:

(a) A system to transport fresh fuel assemblies to a fuelling machine (i.e. a fresh fuel transfer mechanism);
(b) A system to load fresh fuel into the core and to discharge irradiated fuel from the core (i.e. the fuelling machine);
(c) A system to transfer the irradiated fuel assemblies discharged from the fuelling machine into the storage pool water (e.g. elevator and ladder);
(d) Auxiliary crane or hoist in the fuel building;
(e) Fuel handling tools (e.g. a fuel bundle grappler).

GENERAL

4.3. To meet Requirement 14 of SSR-2/1 (Rev. 1) [1], a design basis should be defined for every component and equipment of fuel handling systems and should specify the items listed in para. 3.3, as applicable.

4.4. In operational states and in accident conditions, loads should be limited to ensure that neither fuel damage nor inadvertent criticality is caused and that no damage is caused to the structure of the spent fuel storage pool or the fuel handling equipment.

4.5. Provision should be made in the design of fuel handling systems to avoid dropping, sticking or jamming of fuel assemblies during handling and transfer operations.

4.6. Provision should be made in the design of fuel handling systems to avoid dropping of fuel handling tools during handling operations.

SAFETY FUNCTIONS

4.7. In accordance with Requirement 80 of SSR-2/1 (Rev. 1) [1], fuel handling systems should be designed to maintain subcriticality margins and to avoid fuel damage, high radiation fields and releases of radioactive material exceeding specified limits during fuel handling operations. The contribution of major components and equipment to the fundamental safety functions should be described in a level of detail that is sufficient to enable the design bases to be defined.

POSTULATED INITIATING EVENTS

4.8. Paragraphs 4.9–4.13 provide recommendations on meeting Requirement 16 of SSR-2/1 (Rev. 1) [1].

4.9. Postulated initiating events relevant for the design of fuel handling systems include equipment failures and operator errors that potentially lead to reduction of the subcriticality margin, or to a significant release of radioactive material, or to a significant direct radiation exposure of operating personnel. All such postulated initiating events are required to be considered in the design to establish the preventive measures and protective measures that are necessary to ensure that the required safety functions will be performed (see para. 5.7 of SSR-2/1 (Rev. 1) [1]).

4.10. Where fuel handling constraints are essential for maintaining an adequate margin of subcriticality, operator errors such as misplacement of fuel assemblies and uncontrolled dropping of fuel assemblies should be considered as postulated initiating events.

4.11. The potential dropping of a fuel assembly should be considered as a postulated initiating event. A potential release of radioactive material should be considered with regard to the protection of workers, the public and the environment.

4.12. Fuel misplacement during fuel movement activities within the reactor vessel should be prevented by implementing interlocks of suitable reliability and quality.

4.13. Mechanical damage caused by excessive handling system forces or by dropping of heavy objects should be considered unless these can be prevented by reliable interlocks. Examples of possible handling system actions that could cause damage include fuel assembly hang-up, translation while hoisting or lowering, and the grapple opening under load. Mechanical damage resulting from excessive motion (e.g. continued lowering after seating of the fuel assembly or upward motion into a hard stop) and excessive speed should also be considered.

INTERNAL HAZARDS

4.14. To meet Requirement 17 of SSR-2/1 (Rev. 1) [1] in relation to internal hazards, protection of fuel handling systems should be primarily ensured by the layout of the building in which they are installed.

EXTERNAL HAZARDS

4.15. Paragraphs 4.16–4.18 provide recommendations on meeting Requirement 17 of SSR-2/1 (Rev. 1) [1] in relation to external hazards. Recommendations on the identification of external hazards excluding earthquakes that could affect the design of fuel handling systems are provided in SSG-68 [13]. Recommendations on seismic design are provided in SSG-67 [14].

4.16. Equipment and components of fuel handling systems are required to be designed to withstand the effects of external hazards or to be protected against external hazards and combinations of these hazards (see para. 5.15A of SSR-2/1 (Rev. 1) [1]).

4.17. Protection of fuel handling systems against the effects of external hazards should be primarily ensured by the appropriate design of the building in which they are installed. When the protection is not effective (e.g. as might be the case in the event of an earthquake), handling equipment should be designed to keep its integrity and to not drop loads (e.g. in the event of SL-2 seismic loadings).

4.18. Seismic design specifications for fuel handling systems should be established on the basis of the consequences in terms of potential damage to fuel assemblies (stored or being handled), the release of radioactive material into the building, and the need to operate the equipment during and after an earthquake.

DESIGN LIMITS

4.19. Paragraphs 4.20 and 4.21 provide recommendations on meeting Requirements 15 and 28 of SSR-2/1 (Rev. 1) [1].

4.20. The design should ensure that stresses caused by design load combinations remain below allowable limits established for fuel and for the individual components and equipment of fuel handling systems.

4.21. Limits and conditions for the operation of handling equipment (e.g. limits on lifting capacity and on the speed of lifting, lowering, rotating and traversing, as well as restrictions on the movements of handling equipment) should be defined and interlocks should be provided to ensure that these limits and conditions are not exceeded.

RELIABILITY

4.22. Paragraphs 4.23–4.47 provide recommendations on meeting Requirements 22, 23, 25, 26, 29 and 30 of SSR-2/1 (Rev. 1) [1].

4.23. The necessary reliability for individual items of fuel handling equipment should be defined. This reliability should be specified with account taken of the consequences of the failure of the equipment. The following factors contribute to achieving the necessary reliability:

(a) The safety classification and the associated engineering rules for design and manufacturing of individual structures, systems and components;
(b) Design provisions for monitoring, inspection, testing and maintenance;
(c) The design of command, control and monitoring devices as well as identification markings, actuating elements and connecting elements to safely perform and monitor the fuel handling process;
(d) Devices for communication between the fuel handling areas as well as with the control room.

4.24. The design of load bearing parts of fuel handling systems should be conservative.

4.25. A reliability assessment should be conducted to verify whether the reliability target has been achieved.

STRENGTH ANALYSES FOR ITEMS IMPORTANT TO SAFETY

4.26. Strength analyses should be undertaken to demonstrate that the stresses caused by load combinations are within the design limits established for the individual structures and equipment of fuel handling systems. Typical examples of loads that should be considered in the strength analyses include:

(a) Static loads;
(b) Dynamic loads derived from the normal operation of equipment (e.g. loads from handling equipment at acceleration);
(c) Dynamic loads derived from abnormal operation of equipment (e.g. accidental dropping of a fuel assembly from a maximum height) and from non-symmetrical loads;
(d) Seismic loads defined in accordance with the seismic categorization in SSG-67 [14];
(e) Temperature loads.

4.27. Methods for assessing load combinations should be established in accordance with applicable design codes and standards.

4.28. The strength analyses should credit any equipment that is provided to limit loads (e.g. dampers or shock absorbers), and failure modes for this equipment should also be considered.

SPECIFIC DESIGN RECOMMENDATIONS

4.29. For light water reactors, systems for lifting fuel assemblies should be designed so that abnormal handling and lifting operations cannot result in unacceptable loads on the fuel assembly. This should be ensured by means of physical limitations or by automatic protective actions (either passive or actuated by instrumentation and control systems). Methods that could be used include the following:

(a) Restriction of the power of the hoist motor;
(b) The provision of slipping clutches within drive mechanisms;
(c) Automatic and continuous load sensing and registering devices linked to the hoist motor or cable;
(d) A specified speed limitation.

4.30. Provision should be made in the design for the use of manually operated equipment that is capable of placing fuel assemblies into a safe location in the event of the failure of the normal operating mode of the fuel handling system.

4.31. Handling equipment should be designed to prevent the leakage and escape of lubricants and other fluids or substances that could degrade the purity of the pool water. Such substances either should be prevented from entering wet storage systems or, preferably, should be fully compatible with the fuel and the equipment and storage structures.

4.32. Handling equipment should be designed to prevent the inadvertent emplacement of fuel or core components into a position that is already occupied or into an otherwise inappropriate position.

4.33. The design of fuel handling and refuelling machines can include instrumentation and control systems to manage and monitor fuel handling conducted in the reactor building and in the fuel building. The instrumentation and control systems can be used to help to prevent incorrect movements of the fuel assembly and the emplacement of a fuel assembly into an inappropriate position. The reliability of this system should be commensurate with the safety significance of fuel loading and unloading operations. The consequences of malfunctioning of such instrumentation and control systems should be considered.

4.34. For light water reactors, when the fuel assembly is tilted, loads arising in the fuel assembly structure should be limited by means of supports to ensure that no damage will occur.

4.35. For light water reactors, measures should be provided in the design of fuel handling systems to limit the risk of incorrect positioning of a fuel assembly in the vessel during core refuelling operations.

4.36. For light water reactors, electrical interlocks to prevent movement of the refuelling machine while the fuel is in an incorrect position should be provided.

Specific design aspects for the refuelling machine

Light water reactors

4.37. The hoist gripper of the refuelling machine should be designed to grasp securely and to transport fuel assemblies or other assemblies safely. Consequently, the following safety features and safety systems should be provided:

(a) Before lifting is commenced, a positive indication that the hoist gripper is correctly located on the fuel assembly should be obtained. This should be implemented by the provision of automatic interlocks where feasible. If this is not feasible, strictly controlled administrative procedures should be applied.
(b) The gripper should remain latched in the event of loss of power.
(c) The gripper should not be capable of decoupling from a fuel assembly while the fuel handling machine is exerting a force on the fuel assembly. This should be implemented by using mechanical interlocks.
(d) The gripper should decouple from a fuel assembly only at specified elevations, even when no load is applied. This should be implemented by the provision of automatic interlocks where feasible. If this is not feasible, strictly controlled administrative procedures should be applied.
(e) The gripper should have an integral safety device that prevents the fuel assembly from becoming unlocked.

4.38. Protection devices should be provided to ensure that fuel handling equipment cannot perform horizontal movements during the lifting or lowering of fuel or core components when this could result in the forcing of fuel into position.

4.39. Protection devices (electrical and/or mechanical interlocks) supplemented by administrative measures should be provided to limit the movement of fuel handling machines in order to prevent fuel damage (e.g. overload protection devices to prevent fuel damage, supplemented by the observation of load cell readings to verify that there is no overload).

Pressurized heavy water reactors

4.40. Design provisions should be implemented to provide continuous cooling of the fuel in the event that irradiated fuel bundles become stuck in the fuelling machine and stay for an extended period of time until appropriate action is taken. These provisions should be designed to prevent significant damage to the irradiated fuel bundles or the failure of the fuel elements due to insufficient air cooling.

4.41. In nuclear power plants with on-power refuelling, the designs of the fuelling machine and the interfacing equipment should protect the integrity and function of the reactor coolant circuit, in particular to maintain the pressure boundary and the fuel cooling functions.

4.42. Conditions or failures that could result in a fuelling machine becoming stuck during the refuelling cycle should be anticipated and provisions should be put in place to prevent such an event or else to mitigate the consequences. Provision should be made to manually release the fuel handling machine from a position in which it has become stuck. For designs with on-load fuelling, particular attention should be paid to situations where a fuelling machine could become stuck on channel in a configuration that could result in local flow blockages.

4.43. The design of the fuelling machine should prevent the mechanical loads on fresh fuel, in-core interfacing fuel, interfacing equipment and irradiated fuel from exceeding design limits.

4.44. The fuelling machine should be designed to withstand loads caused by interfacing systems in operational states.

4.45. The fuelling machine should be designed such that contamination of the fuelling machine from the handling of damaged fuel is minimized, and should also be designed so as to facilitate decontamination afterwards.

Specific design aspects for nuclear power plants with a fuel transfer system (pressurized water reactors)

4.46. The fuel transfer system should be designed to ensure adequate cooling of the fuel even during a malfunction of the fuel transfer operation.

4.47. When the spent fuel pool is outside of the containment, design provisions should be implemented to meet the requirements for isolation of the containment (see Requirement 56 of SSR-2/1 (Rev. 1) [1]).

4.48. The design of the fuel transfer system should allow access for safe retrieval of the assembly in a timely manner in the event that the fuel assembly is jammed due to the failure (or malfunction) of the fuel transfer system.

SAFETY CLASSIFICATION

4.49. The equipment and components of fuel handling systems are required to be classified on the basis of their function and safety significance (see Requirement 22 of SSR-2/1 (Rev. 1) [1]).

4.50. The safety classification of handling equipment can be directly derived from the severity of the consequences of equipment failure during handling operations (fuel damage, radiation exposure or release of radioactive material).

4.51. Safety classified equipment should be designed and manufactured in accordance with national or international codes that are appropriate to their safety class. The application of the selected design standards should be justified.

ENVIRONMENTAL QUALIFICATION

4.52. Any prevailing environmental conditions in which the system performs a safety function should be considered in the qualification of fuel handling systems (see Requirement 30 of SSR-2/1 (Rev. 1) [1]). The recommendations provided in paras 3.95–3.100 should be taken into account.

RADIATION PROTECTION

4.53. Lifting equipment for underwater irradiated fuel assemblies should be designed so that the lift is controlled within limits to maintain the minimum depth of water shielding that is necessary.

4.54. Hollow handling tools used under water should be designed so that they fill with water on submersion (to maintain water shielding) and drain on removal.

4.55. In handling fresh fuel (including mixed oxide fuel) containing fissionable material recovered by reprocessing, and which emits significant amounts of radiation, consideration should be given to providing additional shielding to limit the exposure of operating personnel, owing to the higher radiation levels associated with the fresh fuel.

MATERIALS

4.56. Structural materials should be selected on the basis of accepted design codes and standards. Consideration should be given to the potential cumulative effects of radiation on materials likely to be subjected to significant radiation fields.

4.57. Materials in direct contact with fuel should be compatible with the materials of the fuel assemblies and should be such as to minimize chemical and galvanic reactions that might degrade the integrity of the irradiated fuel during its handling.

4.58. Materials used in the construction of fuel handling systems should allow easy decontamination of surfaces.

5. DESIGN BASIS FOR EQUIPMENT USED FOR INSPECTION AND REPAIR OF IRRADIATED FUEL, HANDLING OF DAMAGED FUEL, AND HANDLING AND STORAGE OF IRRADIATED CORE COMPONENTS

EQUIPMENT USED FOR INSPECTION AND REPAIR OF IRRADIATED FUEL AND HANDLING OF DAMAGED FUEL

5.1. Safety measures for handling equipment used for inspection and repair (dismantling and reconstitution) of irradiated fuel, and for handling damaged fuel, should be implemented considering the recommendations provided in Section 4 and applying a graded approach with account taken of the consequences of equipment failure. Specific considerations for typical handling equipment are described in paras 5.2–5.11.

Inspection equipment

5.2. Equipment should be provided for the inspection of fuel assemblies and other core components by visual or other methods.

5.3. Inspection equipment should be designed so as to minimize the effects of irradiation and to prevent overheating of the fuel.

Dismantling and reconstitution equipment

5.4. Appropriate dismantling equipment should be provided if it is necessary to dismantle fuel in order to retain reusable parts such as fuel channels and if the dismantling of the fuel is necessary before storage.

5.5. Dismantling and reconstitution equipment should be designed so as to minimize the effects of irradiation and to prevent overheating of the fuel.

5.6. The dismantling and reconstitution equipment should be designed to preserve the integrity of the fuel rods. The design should prevent possible fuel damage by loads caused by the lifting of dismantled fuel assemblies or fuel rods, by other handling operations such as tilting or by changes to the fuel cladding.

5.7. In the design of dismantling and reconstitution equipment, reliable means should be provided for removing residual heat from the irradiated fuel and from the equipment used to clean the irradiated fuel.

Handling equipment for damaged fuel

5.8. Equipment for the detection of damage to fuel assemblies should be capable of detecting the failure of irradiated fuel assemblies without further impairing the structural integrity of the fuel.

5.9. Provisions should be available to place leaking fuel in appropriate special containers. The containers should be designed to withstand the temperatures and pressures resulting from the residual heat of the irradiated fuel and from chemical reactions between the fuel or its cladding and the surrounding water.

5.10. In the design, consideration should be given to the procedures to be adopted for the removal of damaged fuel assemblies. The special tools for the manipulation of damaged fuel should be designed to ensure an adequate margin of subcriticality, adequate decay heat removal and shielding against radiation. Procedures to permit the use of non-standard equipment should be specified and strict administrative controls should be applied.

5.11. The design of the containers used for encapsulating damaged fuel should be compatible with interim storage. The design should also be compatible with long term storage, or else the containers should be capable of being safely unloaded and the fuel transferred to suitable long term storage containers after the interim storage period.

HANDLING AND STORAGE SYSTEMS FOR IRRADIATED CORE COMPONENTS

5.12. Sometimes irradiated core components that do not contain fuel are stored in the spent fuel storage and handled using the same handling systems designed for irradiated fuel. Irradiated core components include components such as reactivity control devices or shutdown devices, in-core instrumentation, neutron sources, flow restrictors, fuel channels, burnable absorbers and samples of reactor vessel material.

5.13. In general, the recommendations on fuel storage and handling systems provided in Sections 3 and 4 should be followed. Specific considerations for different types of irradiated core component are described in paras 5.14–5.21.

Irradiated core components

5.14. For irradiated core components, particular attention should be paid to the following:

(a) Adequate shielding of irradiated core components should be provided.
(b) Where the inspection of irradiated core components is necessary, interlocks and other measures should be provided, as appropriate, to ensure the protection of operating personnel.
(c) Means of transferring irradiated core components into a suitable shipping container should be provided, where necessary.
(d) Specified storage and disposal systems should be provided, together with inspection systems, where necessary.
(e) Appropriate care should be taken when handling irradiated core components to protect stored fuel and to limit the possible spread of contamination.
(f) Irradiated core components should not be stored in the storage area for unirradiated fuel. If necessary, provision should be made for the temporary storage of such items in the storage facility for irradiated fuel.

5.15. Consideration should be given to the procedures to be adopted for the removal of irradiated core components. The special tools for the manipulation of irradiated core components should be designed to ensure an adequate margin of subcriticality, adequate decay heat removal and shielding against radiation. Procedures to permit the use of non-standard equipment should be specified and strict administrative controls should be applied.

Neutron sources

5.16. Sufficient shielding and monitoring equipment should be provided to protect operating personnel from exposure to radiation from neutron sources. Upon the receipt of transport containers containing neutron sources, contamination checks should be performed, and the transport containers for neutron sources should be clearly marked in accordance with the requirements of the regulatory body.

5.17. Neutron sources should be kept separate from the area for irradiated fuel handling and storage and at a sufficient distance to ensure neutronic decoupling, unless a suitable safety case is provided to ensure adequate shielding or decoupling between source and assemblies.

5.18. Arrangements should be made for the clear identification of all sources and administrative controls should be in place for these sources.

Reusable reactor items

5.19. In most reactor types, there are some core components and fuel assembly items that can be reused (e.g. fuel channels in boiling water reactors or flow restrictor assemblies in pressurized water reactors). These items might be highly activated. If such items are brought to the assembling areas for reuse, the spread of contamination and the radiation exposure of operating personnel should be minimized.

5.20. Reusable components should be capable of being inspected, as necessary, to ensure their dimensional stability and the absence of any damage resulting from operation or handling. Where reusable components contain replaceable items (e.g. seals), it should be possible to inspect the replaceable components.

5.21. The design of the area for storage reusable reactor items should be such as to prevent reusable components from being contaminated with materials that might affect the integrity of reactor components after the reusable components are reinserted.

6. HANDLING OF FUEL CASKS

6.1. The equipment for handling fuel casks should be designed to be compatible with the equipment for lifting fuel and components, and should include the following:

(a) Vehicles for moving casks;
(b) Cranes and associated lifting devices for casks, cask lids and cask internals;
(c) Decontamination equipment;
(d) Radiation monitoring equipment;
(e) Cask draining, flushing, purging and vacuum drying systems;
(f) Tools for disconnection of cask lids;
(g) Cask testing equipment;

(h) Means and devices for preventing the contamination of the external surfaces of casks;
(i) Means for identifying leaking fuel in casks;
(j) Illumination equipment.

Operating aspects of handling fuel casks are described in the Annex.

DESIGN FOR FACILITATING THE HANDLING OF CASKS FOR SPENT FUEL

6.2. The recommendations provided in paras 4.49–4.58 with regard to safety classification, environmental qualification, radiation protection and materials should be applied, as appropriate, to the design of handling equipment for spent fuel casks.

6.3. The spent fuel storage area should be designed to facilitate the handling of spent fuel casks that are to be transported off the site. Recommendations on the design of spent fuel casks are provided in SSG-15 (Rev. 1) [2].

6.4. The design of the spent fuel storage area should include systems for decontaminating the casks before transport or transfer to storage outside the spent fuel storage area. Provision should be made to perform leakage tests, surface contamination tests and other necessary tests on the cask. Provision should also be made for draining the liquids used in decontamination or in flushing the cask coolant system (where relevant) and transferring these liquids to the radioactive waste system.

6.5. The transport route inside the plant should be along a designated safe load path. Passage over stored fuel should be prevented. Stored fuel, the spent fuel pool liner, cooling systems and systems essential to reactor safety should be adequately protected from the dropping or tilting of a fuel cask.

6.6. In accordance with para. 6.67(d) of SSR-2/1 (Rev. 1) [1], fuel handling systems are required to be designed to prevent the dropping of heavy objects, including fuel casks. A cask dropping accident should be prevented with a high level of confidence by means of an appropriate crane design, appropriate procedures for the inspection, testing and maintenance of the crane and the associated lifting gear, and by means of adequate training of operating personnel. If the cask lifting system is such that failure of a single component could result in an unacceptable dropped load, damping devices should be used together with restrictions on the lifting height to mitigate the potential consequences.

6.7. Spent fuel cask handling systems should be designed such as to prevent the dropping of heavy loads during transfer and loading operations and during and after a design basis earthquake.

6.8. The layout of the area for irradiated fuel cask handling should be designed to provide adequate space around the cask for inspection, radiation monitoring and decontamination tests. The necessary storage area for casks and associated equipment (such as shock absorbers) should be provided.

6.9. Administrative means should be implemented to ensure that there is no loading of fuel that has been cooled for an insufficient period of time or of a combination of fuel assemblies that is not permitted in the cask.

EXTERNAL HAZARDS

6.10. The protection of handling equipment for spent fuel casks against external hazards should be primarily assured by the appropriate design of the building in which they are installed. Seismic design specifications for handling equipment for spent fuel cask should be established on the basis of the consequences in terms of the potential damage to fuel assemblies inside the cask and the need to operate the handling equipment during and after an earthquake.

VEHICLES AND CRANES USED IN THE TRANSFER OF FUEL CASKS

6.11. Requirements for overhead lifting equipment are established in Requirement 76 of SSR-2/1 (Rev. 1) [1].

6.12. In accordance with Requirement 80 of SSR-2/1 (Rev. 1) [1], the vehicles or cranes used in the transfer of casks should be designed to limit the possibility of dropping or inadvertently tilting the casks. Vehicles and cranes should be provided with a reliable braking system to ensure that they are not moved unintentionally. Consideration should be given to increasing the reliability of the lifting and transport equipment such that dropping of a load can be treated as a low frequency event, for example, by the use of single failure proof cranes. Suitable speed limitations on the horizontal and vertical movement of the cranes should be provided so as to ensure the safe handling of casks.

6.13. The requirements for the transport of fuel are established in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [25]. To help to ensure compliance with these requirements:

(a) The facility should include radiation monitoring equipment that is capable of measuring gamma radiation, fast neutrons and thermal neutrons from the cask, as appropriate.
(b) Provision should be made to measure surface contamination on the external surfaces of the cask to ensure that the requirements of SSR-6 (Rev. 1) [25] are met before the cask leaves the nuclear power plant.

6.14. If fuel is transported back to the pool from dry storage, adequate cooling of the cask and the fuel should be provided.

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Annex

OPERATING ASPECTS OF HANDLING SPENT FUEL CASKS

A–1. The handling of the spent fuel cask has different aspects depending on which of the following unloading strategies is used:

(a) Unloading with immersion of the cask in the unloading pit;
(b) Unloading with connection of the cask under the unloading pit.

A–2. Unloading with immersion of the cask involves the following actions:

(a) The cask is introduced inside the fuel building on the ground floor by truck or by train.
(b) The shock absorbers of the cask are removed.
(c) The cask is tilted to the vertical using the reception hall crane.
(d) The cask is transferred to the pool floor (e.g. 20 m above the pool floor) to be put into the preparation pit.
(e) After preparation (filling, cooling, precautions against contamination), the cask is handled to the unloading pit.
(f) The cask is immersed by filling the unloading pit with pool water.
(g) The lid is removed to start the unloading of the fuel assemblies.
(h) When the filling of the cask with fuel assemblies is finished, the above process is reversed.

A–3. Unloading with connection of the cask under the unloading pit involves the following actions:

(a) The cask is introduced inside the preparation building.
(b) The shock absorbers of the cask are removed.
(c) The cask is tilted to the vertical using the preparation building crane.
(d) The cask is transferred to the cask wagon.
(e) The wagon is transferred to the fuel building.
(f) After preparation (removal of the lid, filling, cooling) the cask is connected under the unloading pit.
(g) After the connection of the cask, the gate at the bottom of the unloading pit is opened to start the unloading of the fuel.
(h) After the unloading of the fuel is completed, the above process is reversed.

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