IAEA Safety Standards

for protecting people and the environment

Core Management and Fuel Handling for Nuclear Power Plants

Specific Safety Guide

No. SSG-73

IAEA

International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

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

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

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

CORE MANAGEMENT AND FUEL HANDLING 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-73

CORE MANAGEMENT AND FUEL HANDLING FOR NUCLEAR POWER PLANTS

SPECIFIC SAFETY GUIDE

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FOREWORD

by Rafael Mariano Grossi
Director General

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

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

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

Safety measures and security 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.

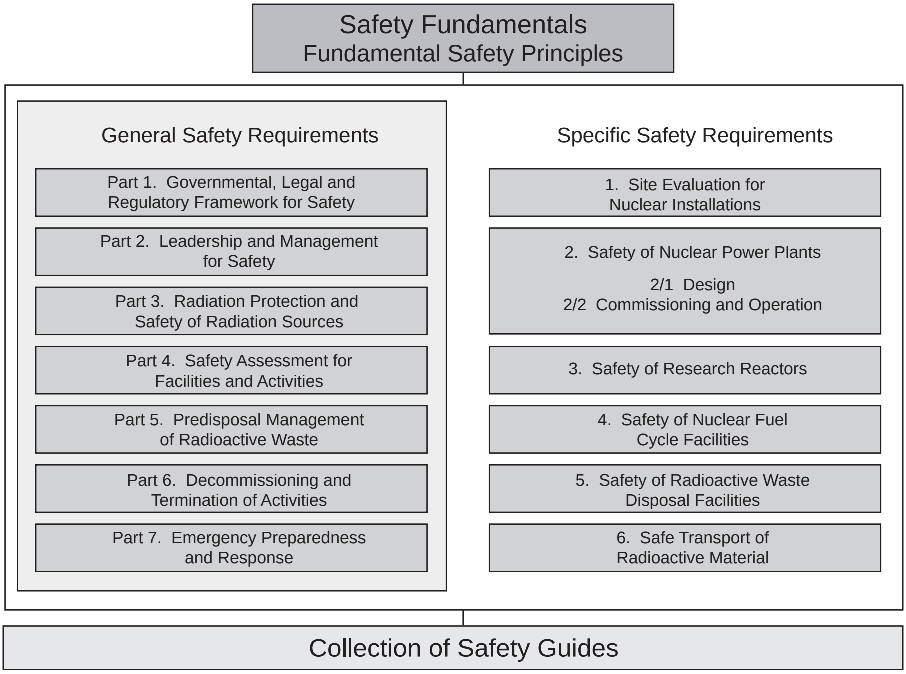

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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.

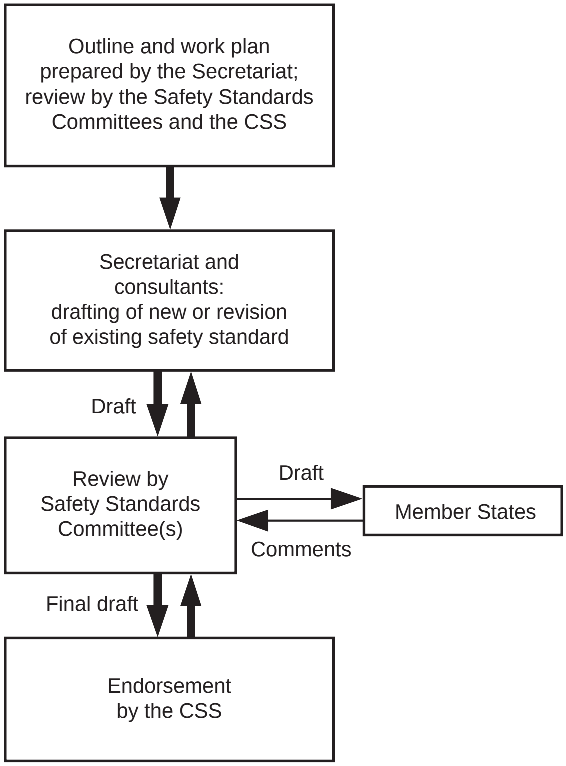

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 https://www.iaea.org/resources/safety-standards/safety-glossary). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

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

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

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

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1. INTRODUCTION

BACKGROUND

1.1. Requirements for the operation of nuclear power plants are established in IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation [1], while requirements for the design of nuclear power plants are established in IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [2].

1.2. This Safety Guide provides specific recommendations on core management[1] and fuel handling[2] for nuclear power plants to ensure the safe and reliable use of the nuclear fuel in the reactor.

1.3. This Safety Guide was developed in parallel with six other Safety Guides on the operation of nuclear power plants, as follows:

— IAEA Safety Standards Series No. SSG-70, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants [3];
— IAEA Safety Standards Series No. SSG-71, Modifications to Nuclear Power Plants [4];
— IAEA Safety Standards Series No. SSG-72, The Operating Organization for Nuclear Power Plants [5];
— IAEA Safety Standards Series No. SSG-74, Maintenance, Testing, Surveillance and Inspection in Nuclear Power Plants [6];
— IAEA Safety Standards Series No. SSG-75, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants [7];
— IAEA Safety Standards Series No. SSG-76, Conduct of Operations at Nuclear Power Plants [8].

A collective aim of this set of Safety Guides is to support the fostering of a strong safety culture in nuclear power plants.

[1] In this publication, 'core management' refers to the activities associated with fuel management in the core and with reactivity control.

[2] In this publication, 'fuel handling' refers to the receipt of fresh fuel; the movement, storage and control of fresh and irradiated fuel; and the handling of fuel packages in the spent fuel pool.

1.4. The terms used in this Safety Guide are to be understood as defined and explained in the IAEA Safety Glossary [9].

1.5. This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-2.5, Core Management and Fuel Handling for Nuclear Power Plants[3].

OBJECTIVE

1.6. The purpose of this Safety Guide is to provide recommendations on core management and fuel handling activities at nuclear power plants to meet the relevant requirements established in SSR-2/1 (Rev. 1) [2] and Requirement 30 of SSR-2/2 (Rev. 1) [1]. These activities are necessary in order to allow optimum reactor core operation without compromising the limits imposed by the design safety considerations relating to the nuclear fuel and to the plant as a whole.

1.7. The recommendations provided in this Safety Guide are aimed primarily at operating organizations of nuclear power plants and regulatory bodies.

SCOPE

1.8. It is expected that this Safety Guide will be used primarily for land based stationary nuclear power plants with water cooled reactors designed for electricity generation or for other production applications (such as district heating or desalination).

1.9. This Safety Guide covers the safety objective of core management and the basic tasks of the core management programme. The receipt of fresh fuel, the storage and handling of fuel assemblies and core components[4], the loading and unloading of fuel assemblies and core components, and the insertion and removal of other reactor materials are also within the scope of this Safety Guide.

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Core Management and Fuel Handling for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.5, IAEA, Vienna (2002).

[4] A ‘fuel assembly’ is a set of fuel elements and associated components that are loaded into and subsequently removed from a reactor core as a single unit [9]. ‘Core components’ are the elements of a reactor core, other than fuel assemblies, that are used to provide structural support of the core construction, or the tools, devices or other items that are inserted into the reactor core for core monitoring, flow control or other technological purposes and are treated as core elements [9].

1.10. This Safety Guide covers the preparations for the dispatch of irradiated fuel from the site. Transport, off-site storage and disposal of irradiated fuel and core components are outside the scope of this publication.

1.11. Aspects of fuel accounting not directly relating to nuclear safety are not considered in this publication; thus, the State system for accounting for and control of nuclear material is outside the scope of this Safety Guide.

STRUCTURE

1.12. Recommendations on the core management and monitoring programme for the safe use of the nuclear fuel are provided in Section 2. Section 3 provides recommendations on managing the handling and storage of fresh fuel. Section 4 provides recommendations on the implementation of the refuelling programme to preserve fuel integrity. Recommendations on the handling, storage and inspection of irradiated fuel are provided in Section 5. Section 6 provides recommendations on the handling and storage of core components. Section 7 provides general recommendations on the preparatory arrangements for dispatch of fuel from the site. Sections 8 and 9 describe the responsibilities of the operating organization for administrative and organizational aspects and documentation in relation to core management and fuel handling.

2. CORE MANAGEMENT

OBJECTIVE OF CORE MANAGEMENT

2.1. The objective of core management is to ensure the safe and reliable use of the nuclear fuel in the reactor on the basis of the safety analysis, with due consideration of the limits imposed by the design of the fuel and of the plant. Recommendations on design are provided in IAEA Safety Standards Series No. SSG-52, Design of the Reactor Core for Nuclear Power Plants [10], and recommendations on the safety analysis are provided in IAEA Safety Standards Series No. SSG-2 (Rev. 1), Deterministic Safety Analysis for Nuclear Power Plants [11]. For maximum efficiency, heat flux and coolant temperatures need to be as high as possible, while at the same time the key parameters need to be kept within operational limits. Because of this, high levels of expertise and meticulous control of the associated operations are essential.

2.2. The concept of defence in depth is required to be applied to core management (see para. 2.12 of SSR-2/1 (Rev. 1) [2]). The application of this concept should cover a number of operational precautions within the levels of defence (e.g. thorough planning of core management activities, equipment and procedures, core analysis and monitoring, fuel integrity monitoring, contingency measures) aimed at ensuring fuel integrity, preventing accidents and ensuring appropriate protection if an accident were to occur.

2.3. Although the specific details of core management are dependent on the reactor type and plant organization, in all cases the core management programme should meet the following objectives:

(a) To provide the means to perform core management functions effectively throughout the lifetime of the fuel in order to ensure that core parameters remain within the approved operational limits. Core management functions include the following:
   (i) Core performance monitoring (including provision of redundancy for key instruments and procedures for dealing with loss of functions);
   (ii) Thermomechanical evaluation;
   (iii) Making fuel depletion calculations, reactivity calculations, neutronic calculations and thermohydraulic state calculations.
(b) To provide support for core operating strategies in order to obtain maximum operating flexibility and optimum fuel utilization, while remaining within the established safety limits.
(c) To ensure that only fuel assemblies of an approved design are handled.

2.4. The basic core management tasks to be undertaken to ensure the safe use of fuel in the core include the following:

(a) Procuring fresh fuel in accordance with paras 7.18 and 7.19 of SSR-2/2 (Rev. 1) [1] (see also the recommendations provided in appendix III to IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [12]);
(b) Ensuring the integrity of the fuel by maintaining relevant core operating parameters in accordance with operational limits and conditions (see paras 7.20–7.25 of SSR-2/2 (Rev. 1) [1]);
(c) Securing the ability to shut down the reactor from any operational state (including transient conditions);
(d) Unloading fuel when its specified burnup or dwell time limit has been reached, or if operating experience (e.g. of corrosion, leakage, bowing) necessitates earlier unloading;

(e) Avoiding loading fuel and other core components that might potentially degrade to a level where an additional radiological risk could be created before the scheduled unloading;
(f) Providing safety justification before allowing any fuel assembly to exceed its limiting conditions;
(g) Detecting failed fuel, and unloading such fuel if necessary;
(h) Updating plant operating strategies on the basis of fuel performance and operating experience from the plant and from other plants, as well as further progress in science and technology;
(i) Assessing the safety implications, including seismic and dynamic responses, of any component or material proposed for insertion into the core or the reactor vessel;
(j) Assessing the effects of irradiation on core components, adjacent reactor internals and the reactor pressure vessel.

ANALYSIS OF CONDITIONS AND CHARACTERISTICS OF THE REACTOR CORE

2.5. Core analysis should be performed in accordance with the recommendations provided in SSG-52 [10].

2.6. Reactor core analysis should be carried out at appropriate times throughout the operating lifetime of the reactor to ensure that the operational strategy and the limitations on operation do not violate any design limits appropriate to each plant state.

2.7. Reactor core analysis should be performed to cover the entire operating cycle for a variety of operational states and core conditions, such as the following:

(a) Full power, including representative power distributions;
(b) Load following (as applicable);
(c) Stretch-out[5];
(d) Approach to criticality and power operation;
(e) Power cycling;
(f) Startup;
(g) Refuelling;

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[5] Stretch-out is used in some reactors to allow power operation beyond the natural end of the burnup cycle, where the decrease in reactivity associated with burnup is compensated by gradually reducing power and temperature levels.

(h) Shutdown;
(i) Anticipated operational occurrences;
(j) Operation at and beyond the thermohydraulic stability boundary (for boiling water reactors).

2.8. Whenever the management of fuel in the core is changed, or any characteristics of core loading patterns or the fuel elements (such as the fuel enrichment, fuel element dimensions, fuel element configuration or fuel cladding material) are changed, a new safety analysis should be performed and documented to demonstrate compliance with the acceptance criteria for the fuel.

2.9. The reactor core analysis should include an analysis of fuel element performance (based on average and local power levels, and axial temperature or void distributions) to demonstrate that the respective thermal and mechanical fuel design limits are met for normal operation, anticipated operational occurrences and design basis accidents without core melt. Fuel element performance analysis should take into account the power and burnup distributions along the radius of fuel pellets. For light water reactors, the reactor core analysis should include peak channel power and peak linear power rates at each assembly location and axially along each fuel assembly, for normal full power operation and for steady state power distributions. The effects of changes in the geometry of a fuel assembly on neutronic and thermohydraulic performance (e.g. changes due to bowing of the assembly) should be taken into account. The reactor core analysis should also include the radial power distribution within a fuel assembly and the axial power distortion due to spacers, grids and other components, in order to identify localized higher values and to evaluate the local power levels.

2.10. The types of fuel in use should be taken into account in the analysis of core conditions. Neutronic, thermohydraulic, chemical and mechanical analyses should be performed as part of a detailed core analysis, which should include the following core parameters for both steady state and transient conditions:

(a) Variations in reactivity with burnup of the fuel and the actions needed to maintain core reactivity (e.g. changes in control rod positions, neutron absorbers, coolant temperature and void content, or refuelling rate);
(b) Location and reactivity worth of all control rods or rod groups;
(c) The rate of change of the concentration of soluble absorber in the moderator and the coolant;
(d) Impact on reactivity of temperature (of the fuel, moderator and coolant), power, boron concentration (in pressurized water reactors), pressure

and void, for all modes of normal operation and for anticipated transient conditions and design basis accidents;
- (e) The neutron flux and distribution of power in the core and within the fuel assemblies, and the control of these parameters by appropriate movement of control rods or zonal absorbers;
- (f) Fuel and moderator temperatures, coolant flow rates, coolant chemical conditions, pressure drop, and temperature, density and thermal margins of the coolant;
- (g) Stability of the power distribution;
- (h) Changes in xenon concentration due to transients;
- (i) Minimum boron concentration ensuring the subcriticality margin in shutdown states (for pressurized water reactors);
- (j) Growth of oxidation and hydriding of the cladding over the lifetime of the fuel;
- (k) Changes in the delayed neutron fraction and prompt neutron lifetime.

2.11. Changes in the parameters listed in para. 2.10 and the effects of these changes should be predicted for both steady state and transient conditions. The results of such predictions should be compared with measured parameters, as far as practicable, and should be used to confirm that there is sufficient capability for control at all times to ensure that the reactor can be shut down safely and remain shut down following any normal operation, anticipated operational occurrence or design basis accident, with predefined failures taken into account.

2.12. During reactor operation, the following items should be considered, as appropriate:

- (a) Variations in the reactivity worth of control rods due to irradiation effects, temperature effects and boron concentration changes (in pressurized water reactors);
- (b) The effects of irradiation and control rod shadow effects on neutron flux detectors, particularly the variation in sensitivity;
- (c) The adequacy of the neutron source strength and the sensitivity and location of neutron detectors for startup, especially following a long shutdown (the irradiated fuel and photoneutrons might not constitute a source of sufficient strength).

2.13. If there is a significant discrepancy between the measured and calculated values of core parameters, the following actions should be taken in the order indicated:

(1) Make the reactor safe (by shutting it down, if necessary).
(2) Identify the root cause of the discrepancy.
(3) Perform any necessary corrective actions (including those necessary to prevent recurrence).

COMPUTATIONAL METHODS FOR CORE CALCULATIONS

2.14. The operating organization should ensure that appropriate numerical methods and techniques are available and can be used to predict the behaviour of the reactor during operation, to ensure that it will be operated within operational limits and conditions. Computational models, numerical methods and nuclear data should be verified, validated, benchmarked, amended and kept up to date, as necessary. The uncertainties in computational results and in measurements should be taken into account.

2.15. Where possible, validation tests should be performed without prior knowledge of the experimental results, in order to preclude any deliberate tuning of code calculations to yield better agreement with experimental results.

2.16. Independent verification of computational results (ideally, using diverse people, tools and methods) should be performed for significant core management calculations. Special emphasis should be placed on the qualification of methods to address items such as extended burnups, new materials, design modifications and power upratings. Further recommendations on the verification and validation of computer codes used for purposes of safety analysis are provided in SSG-2 (Rev. 1) [11].

2.17. All modifications to the software and databases used for core calculations should be reviewed and evaluated for their potential impact on the operation of the core. Such modifications should be independently verified and validated, and functionally tested in accordance with standard methods and procedures for the management and control of software, which could include approval by the regulatory body before implementation. Physical and/or administrative controls should be established to ensure the integrity and reliability of associated computer programs and databases.

2.18. The operating organization should ensure that personnel performing core calculations are qualified and properly trained.

OPERATION OF THE REACTOR CORE

2.19. To ensure safe operation of the reactor core, an effective core operation programme should be established. Optimization of fuel utilization and flexibility in core operation should not compromise safety. The core operation programme should include the operating procedures and engineering practices that are intended to ensure the following:

(a) That all pre-startup procedural requirements are met and functional tests are completed, and that all necessary documents and/or procedures are updated, prior to reactor startup;
(b) That the necessary measurements of criticality and shutdown margin, the low power physics tests, the core physics measurements and the power raising tests are all performed during reactor startup;
(c) That a surveillance programme for all necessary in-core fuel management and reactivity management functions is established and implemented.

2.20. To ensure safe operation of the reactor core, the following properties and conditions should be taken into consideration:

(a) The conformance of fresh fuel to design specifications;
(b) Fuel loading patterns;
(c) Fuel burnup and irradiation records;
(d) The reactivity shutdown margin;
(e) Heat transfer, coolant flow, pressure, temperatures, water level (for boiling water reactors) and thermal margins;
(f) Rates of addition and removal of reactivity;
(g) Coefficients of reactivity;
(h) The worth of control rod banks and dissolved boron (for pressurized water reactors), or the worth of control rod banks and recirculation flow rate (for boiling water reactors);
(i) The characteristics of the control and protection systems;
(j) Neutron flux and power distribution;
(k) Core stability (considering, in particular, permitted ranges of core operation and possible xenon transients);
(l) Heat dissipation from the core to the ultimate heat sink in all operational states and in accident conditions;

(m) Coolant and moderator chemistry and moderator condition;
(n) Ageing effects resulting from irradiation and thermal stresses;
(o) Fission product activity in the primary coolant and the off-gas system;
(p) Degradation of the fuel cladding (e.g. due to oxidation or to deposition of crud);
(q) Degradation of the thermomechanical properties of fuel with burnup;
(r) Acceptable power ramp rates;
(s) Foreign material intrusion.

2.21. In the operating procedures for the reactor core, the following should be taken into consideration, as appropriate:

(a) Identification of the instruments and the calibration and assessment methods to be used by the control room operators, so that the relevant reactor parameters can be monitored within a range that is consistent with the limits imposed by the design of the fuel and of the plant, and the safety analysis;
(b) Pre-startup checks, including of the fuel loading pattern, coolant flow and temperature, and pressure circuit integrity;
(c) Alarm and safety settings to avoid damage to the fuel, the core or the primary circuit, allowing for changes in core conditions due to fuel burnup or refuelling;
(d) The operating history of each fuel assembly, especially before refuelling;
(e) Parameters to be recorded for comparison with predictions of core conditions;
(f) Limits for the chemical parameters of the primary coolant and moderator;
(g) Limits for the primary coolant flow;
(h) Limits on the rate of power raising;
(i) Limits on power densities and flux tilts;
(j) Actions to be taken when the limits are reached;
(k) Control rod patterns and sequencing;
(l) Actions to be taken in the event of control rod malfunction;
(m) Criteria for determining fuel failure and the actions to be taken when failure is indicated;
(n) Recriticality temperature of the core during transition from a hot shutdown state to a cold shutdown state including consideration of cooling gradient (pressurized water reactors).

2.22. With the aim of protecting fuel against pellet–cladding interactions, the supplier’s recommendations on power manoeuvring should be complied with; any exceptions should be justified in the safety documentation. The appropriate restrictions in terms of prescribed preconditioning, limitations on operating time at reduced power (to limit fuel deconditioning[6]), ramp rates and power level holds (to prevent excessive pellet–cladding interaction for the load following operation) should be addressed. Special attention should be given at the first startup after handling of the fuel assemblies, when more severe power ramp rates are applied.

2.23. The core power should be controlled globally and locally in such a way that the peak linear heat rate of each fuel element and the minimum critical heat flux ratio are kept within the appropriate limits (depending on axial position and burnup) for the operating conditions anywhere in the core. Variations in the power distribution caused by local variations in reactivity (e.g. due to xenon instability, changes in coolant conditions or changes in the positions and characteristics of flux detectors) should be taken into account in the power evolutions.

2.24. Following power changes, any discrepancies between the actual plant response and the predicted plant response should be immediately investigated, fully understood and resolved in a timely manner.

2.25. Reliable core cooling is a fundamental safety function and is required to be ensured for all plant states (see Requirement 4 of SSR-2/1 (Rev. 1) [2]). Means of monitoring the status of core cooling are required to be provided (see para. 4.2 of SSR-2/1 (Rev. 1) [2]).

2.26. Probabilistic safety assessment indicates that shutdown modes could be significant contributors to core damage frequency. Therefore, during shutdown, special care should be taken to ensure that reactor subcriticality margins and reliable long term core cooling are maintained at all times.

REACTIVITY MANAGEMENT PROGRAMME

2.27. Paragraph 7.20 of SSR-2/2 (Rev. 1) [1] states:

> "The operating organization shall be responsible for establishing a safe reactivity management programme under a strong management system for quality. Decisions on, and the planning, evaluation, conduct and control of, all operations or modifications involving the fuel that are liable to affect reactivity control shall be undertaken by using approved procedures and respecting predefined operational limits for the core."

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[6] When power is lowered for a long time, the cladding slowly resticks through creep. This mechanism, which takes some hours to a few days, is called deconditioning.

2.28. The reactivity management programme should ensure the integrity of the barriers that prevent fission product release. The reactivity management programme should include all the activities that ensure that core reactivity and stored nuclear fuel (where the potential for criticality exists) are monitored and controlled in accordance with operational limits and conditions. The following aspects should be addressed in the reactivity management programme:

(a) Nuclear fuel should be operated, handled and stored in a monitored and defined condition within the operational limits and conditions for the fuel and the reactor core.
(b) Control rods and the concentration of soluble absorbers should only be manipulated in a deliberate, carefully controlled manner, while the reactor response is monitored closely.
(c) Reactivity changes and manipulations are required to be made in a deliberate and carefully controlled manner using dedicated procedures to ensure that the desired response is achieved (see para. 7.22 of SSR-2/2 (Rev. 1) [1]).

2.29. Reactivity monitoring strategies and operating procedures should be developed as part of the reactivity management programme. Plant personnel should be trained to understand the strategies and be capable of implementing the procedures. The importance of maintaining margins to operational limits for the reactor core should be highlighted as part of the management's expectations. Emergency operating procedures and measures should be developed for situations in which reactivity management issues occur.

2.30. Independent reviews of the implementation of the reactivity management programme should be performed.

2.31. Further recommendations on reactivity control during operations of nuclear power plants are provided in SSG-76 [8], and recommendations on the core reactivity characteristics and the means of control of reactivity are provided in SSG-52 [10].

CORE MONITORING PROGRAMME

2.32. Paragraph 7.21 of SSR-2/2 (Rev. 1) [1] states:

> "A comprehensive core monitoring programme shall be established to ensure that core parameters are monitored, analysed for trends and evaluated to detect abnormal behaviour; to ensure that actual core performance is

consistent with core design requirements; and to ensure that the values of key operating parameters are recorded and retained in a logical, consistent and retrievable manner."

2.33. Important core parameters should be monitored continuously in the control room, with more detailed measurements taken at a suitable frequency during core operation to ensure that these parameters remain within operational limits and conditions and that any corrective action can be taken when necessary. Where detailed information is available in the control room, the validity of this information should be confirmed by periodic surveillance commensurate with the safety significance of the monitoring function.

2.34. With the reactor operating at power, core conditions should be monitored and compared with predictions to determine whether they are as expected and are within operational limits (see SSG-70 [3]). If the core conditions do not conform, appropriate action should be taken to maintain the reactor in a safe condition. The results of core monitoring and testing should also be taken into account in the review and updating of the refuelling programme and the optimization of core performance. The parameters to be monitored (either continuously or at appropriate intervals), analysed for trends and evaluated should include the following, as appropriate:

(a) Axial, radial and azimuthal neutron flux or power peaking factors.
(b) Rate of change of neutron flux.
(c) Positions and patterns of control rods and zonal neutron absorbers.
(d) Concentrations of soluble boron (or ^{10}B content when enriched boron is used) in the coolant and/or moderator (for pressurized water reactors).
(e) Water level in the reactor vessel and saturation margin (for pressurized water reactors).
(f) Operability and response characteristics of devices for reactivity control, and of other significant means of controlling reactor power.
(g) Reactivity as a function of control rod position or moderator level.
(h) Scram time, dump valve opening time, dump time and absorber injection time following each reactor trip.
(i) Pressure, flow and temperature rise of the coolant and the coolant outlet temperatures in the primary and secondary circuits.
(j) Average zonal and/or sector coolant outlet temperatures and power tilt factors.
(k) Assessed values for the following:
    (i) Thermal power output from the core;
    (ii) Fuel temperature;

(iii) Heat generation in the moderator;
(iv) Minimum critical power ratio (boiling water reactors);
(v) Departure from nucleate boiling ratio (pressurized water reactors);
(vi) Limits on the linear heat generation rate.

(l) Moderator temperature and peak channel mass flow.
(m) Fission product activity in the primary coolant or the off-gas system.
(n) Physical and chemical parameters of the moderator and primary coolant, such as pH, conductivity, the amount of crud and the concentration of impurities and products of radiolytic decomposition.
(o) Isotopic composition of absorbers in the primary coolant and moderator.

2.35. Core conditions following startup, on-load refuelling and shutdown should be carefully assessed to ensure the following:

(a) The reactivity and control rod configurations are correct.
(b) The channel flows are correct.
(c) The pressure vessel and major structural components are performing normally.
(d) The coolant temperatures are as expected.

2.36. Suitable instrumentation should be provided and maintained for monitoring core parameters such as the core power (e.g. level, distribution, time dependent variation), the conditions and physical properties of the coolant and moderator (e.g. flow rate, temperature), and the expected efficiency of the means of shutdown of the reactor (e.g. the insertion depth of the absorber devices compared with their insertion limits), so that any necessary corrective action can be taken. The instrumentation to be used for core monitoring should be appropriately qualified. Recommendations on equipment qualification are provided in IAEA Safety Standards Series No. SSG-69, Equipment Qualification for Nuclear Installations [13].

2.37. The instrumentation for monitoring the core parameters should normally meet the following criteria:

(a) Have adequate range overlap at all power levels from the source range to full power;
(b) Have suitable sensitivity and response time, range and calibration for all operational states and, where appropriate, for accident conditions;
(c) Provide the necessary information on the spatial variation in values of the parameters needed for evaluation of the status of the core;

(d) Facilitate the evaluation of core performance and the assessment of abnormal situations by the control room operators.

2.38. To detect control rod anomalies or reactivity control disturbances or degraded core cooling in all relevant reactor operational states, core monitoring should be capable of the following:

(a) Detection of control rod anomalies (e.g. stuck, misaligned, over-inserted or dropped control rods);
(b) Detection of inadvertent boron (or other soluble absorber) dilution phenomena;
(c) Detection of core cooling anomalies (e.g. cooling asymmetry, degraded cooling conditions, fuel channel flow degradations, disruption of natural circulation).

2.39. The monitoring strategy should be appropriately adjusted for load following regimes (i.e. regimes that increase the constraints on core equipment). Monitoring of equipment fatigue should be performed (e.g. temperature measurements, non-destructive materials tests), especially on items important to safety. Special attention should be given to the monitoring of the control rod mechanisms and thermal and core parameter fluctuations.

2.40. Core parameters such as coolant temperature, coolant pressure, coolant flow and neutron flux distribution should be measured and displayed in an appropriate manner to control room operators. Where applicable, changes in the core due to refuelling and fuel burnup might necessitate changes in alarm levels and in safety system settings. For operation at reduced power or in the shutdown state, consideration should be given to the need to adjust the set points for alarms or for the initiation of corrective actions, in order to maintain the appropriate safety margins.

2.41. In many cases, the parameters that affect fuel behaviour are not directly measurable. In such cases, values for these parameters should be derived by analysis from measured parameters such as neutron flux distribution and temperatures, pressures and flow rates. These derived values are used as a basic input for establishing the operational limits and conditions. The values of parameters specified for use by control room operators should be given in terms of instrument indications.

2.42. Methods and acceptance criteria should be established for assessing measured core parameters and for correlating them with other parameters important to safety that cannot be measured directly, such as the internal temperatures of fuel, cladding and components, internal rod pressures and critical heat fluxes. The results of the assessment and correlation should be recorded, and these results should form the basis for appropriate corrective actions to be taken to ensure compliance with operational limits and conditions.

2.43. The values of certain parameters, such as those relating to chemical control, are derived either from direct measurements or from periodic analyses of samples of coolant, moderator or cover gas. Operating personnel should be regularly informed of the results of these measurements and analyses, and should be provided with instructions concerning the actions to be taken if these parameters approach pre-established limits.

ENSURING FUEL INTEGRITY

General

2.44. The operating organization is required to ensure that the fuel has been adequately designed and has been manufactured in accordance with design specifications, and that only approved fuel is loaded into the core (see para. 7.18 of SSR-2/2 (Rev. 1) [1]).

2.45. Prior to insertion or reinsertion, the fuel should be inspected to ensure that it meets established acceptance criteria intended to ensure that damaged or failed fuel is not loaded into the core. The inspection programme should include, as appropriate, means for the detection of cladding oxidation, crud deposition and fuel element bowing to identify abnormal degradations.

2.46. A fuel integrity monitoring programme should be established and implemented. This programme should include the monitoring of fuel operating parameters, the use of lead test assemblies, the inspection of irradiated fuel and, in special cases, examinations in hot cells. The operating organization should establish and implement a process to identify the causes of any fuel failure.

2.47. The fuel integrity monitoring programme should include appropriate procedures and engineering practices, such as the following:

(a) Implementing operating strategies that minimize the potential for fuel failures;

(b) Ensuring that radiochemistry data indicative of fuel cladding integrity are systematically analysed for trends and evaluated to detect anomalous behaviour, as required by para. 7.24 of SSR-2/2 (Rev. 1) [1];
(c) Implementing an action plan for failed fuel.

2.48. The fuel integrity monitoring programme should be developed so as to keep occupational exposure as low as reasonably achievable, in accordance with Requirement 11 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [14].

Fuel integrity monitoring

2.49. An important indication of fuel failure is an increase in fission product activity above the normal value in the primary coolant (or the off-gas system). Monitoring of fission product activity in the coolant should be performed routinely by means of on-line instrumentation, by measurement of the levels of fission product activity in samples or by both techniques. Investigations of specific radionuclides should be made to characterize failures.

2.50. The normal level of fission product activity in the reactor coolant should be specified during the initial period of reactor operation following startup in order to provide a reference background level.

2.51. For reactors designed for on-load refuelling, an upper limit for the fission product activity in the reactor coolant should be specified, above which a fuel failure will be assumed to have occurred. Where applicable, a scanning system (such as a delayed neutron monitoring system) should be used to locate the failed fuel. If the scanning system has provisions for monitoring coolant from a single channel and groups of channels, a value for the ratio of activity in a single channel to that in its group should be specified and used to determine whether the channel contains failed fuel.

2.52. The integrity of all parts of the fuel assembly should be checked by monitoring, where appropriate. In particular, highly stressed components in the lifting load path for on-load refuelling that are subject to temperature cycling or other stresses should be carefully examined to ensure long term safety.

Action planning for failed fuel

2.53. A plan for contingency action in the case of fuel failure should be established and implemented. This plan should contain the following elements:

(a) Action levels for investigation activities that focus on fuel failure;
(b) Action levels to restrict power operations, in order to preclude additional fuel damage and to prevent exacerbation of any existing fuel damage;
(c) Measures to identify leaking fuel assemblies and to remove them from service;
(d) Measures to determine the cause of the loss of fuel integrity;
(e) Measures to remedy the causes of fuel damage;
(f) Fuel inspection activities;
(g) Fuel reconstitution activities;
(h) Review of operating experience to prevent future failures from the same root cause.

2.54. For reactors designed for on-load refuelling, operating instructions should be established that specify levels at which corrective actions should be taken. Failed fuel should be unloaded so that the background fission product activity will remain low enough to permit detection of future failures, to minimize contamination of the coolant and the primary coolant circuit, and to prevent subsequent fuel damage (such as damage due to the formation of oxide or hydride mounds). The refuelling plan (see para. 4.1) should be reviewed to determine whether it should be modified as a result of unloading of the failed fuel.

2.55. Generally, reactors designed for off-load refuelling permit continued operation at power with a very limited amount of failed fuel. The criteria for shutting down the reactor to remove failed fuel are usually based on the maximum permissible off-gas activity or the maximum permissible fission product activity in the coolant system in order to minimize the actual or potential exposure of workers and the public. In-core or out-of-core sipping tests (and, if necessary, ultrasonic inspection) should be used to find failed fuel. Failed fuel should not be reused without first being repaired or reconstituted. The core design should be reviewed to determine whether changes are needed as a result of the removal of failed fuel.

Tracking of fuel history

2.56. The fuel history should be recorded in order to consider all relevant aspects of fuel performance, such as the following:

(a) Fuel design and operational characteristics;
(b) Fuel operating history, including information about any abnormal operating conditions;
(c) Burnup history and associated core locations;
(d) Coolant chemistry history;
(e) The chronology of fuel cladding defects, including their initial indication, root cause evaluations and completion of corrective actions.

New designs of fuel or modifications to fuel

2.57. If fuel of a new design or modified fuel is to be introduced into the core, the operating organization is responsible for ensuring that the fuel meets the design requirements and that any safety related effects of this fuel on core operations are thoroughly investigated and understood (see para. 7.18 of SSR-2/2 (Rev. 1) [1]). Prior to operating a core with more than one type of fuel, the operating organization should ensure that the fuel of new design or the modified fuel, whichever the case may be, is compatible with the existing fuel and other core components, and that the operating personnel responsible for core management have access to all the relevant information.[7]

2.58. Appropriate licensing documentation should be prepared for the fuel of a new design or modified fuel. This documentation should include the following:

(a) Information on the fuel design and on input data for the prediction and monitoring of core behaviour;
(b) Results of the analyses and testing that were used to develop correlations for monitoring thermal margins;

[7] It is good safety practice to consider the use of a new fuel assembly in a step by step approach, gradually increasing the number of fuel assemblies loaded and the number of reactors involved. Moreover, it is advisable to adopt a cautious approach for any modification of a fuel assembly design, by following successive and progressive steps: (1) Obtaining sufficient and relevant feedback before proceeding to the irradiation in-reactor; (2) Starting with a few lead test assemblies up to fuel loads in one and then in several reactors.

(c) Verification of thermomechanical, mechanical, thermohydraulic and neutronic limits for design compatibility;
(d) Analysis of the effects of transients on the fuel.

2.59. To assess the behaviour of fuel of a new design or of a modified fuel under the conditions expected in subsequent use, a lead test assembly programme should be considered, in which all available operating experience is taken into account. Such a programme should include the following:

(a) Testing the administrative measures and procedures, and tools and equipment for handling the fuel of a new design;
(b) Monitoring the performance of the fuel of a new design, including corrosion, thermomechanical and mechanical effects;
(c) Gaining operating experience of using more than one fuel type in the core.

2.60. Feedback from experiments and research and development programmes covering power ramp tests, reactivity-initiated accident tests and loss of coolant accident tests (analytical or global) should be taken into account when determining the behaviour of fuel of new designs for operational states and accident conditions.

2.61. Care should be taken by the operating organization in considering changing to a new supplier, to ensure that the quality of the fuel assembly is not adversely affected and that supporting analysis is maintained (if applicable).

REFUELLING PROGRAMME

2.62. The operating organization is required to establish a fuelling programme (see para. 7.19 of SSR-2/2 (Rev. 1) [1]). There should be strict control of core loading, unloading, shuffling and on-load refuelling operations.

2.63. All core alterations are required to comply with approved configurations (see para. 7.19 of SSR-2/2 (Rev. 1) [1]). Throughout such changes, core reactivity should be monitored to prevent an inadvertent criticality. All fuel movements are required to be in accordance with detailed, approved procedures (see para. 7.26 of SSR-2/2 (Rev. 1) [1]). Intermediate fuel patterns should be no more reactive than the most reactive configuration considered and approved in the design.[8] There should be a method of checking that fuel movements will not conflict with each other, and it should be possible to retrospectively trace the actual fuel movements made, if necessary.

2.64. The refuelling programme should include details of the core pattern and a schedule of movements of core components (i.e. fuel assemblies, control rods, burnable absorbers and flux shaping absorbers) into and out of the reactor. The necessary checks during refuelling to verify the correct performance of different activities should also be included in the refuelling programme.

2.65. In achieving full power and the target rate for fuel burnup, and in providing sufficient reactivity to compensate for fuel depletion and the buildup of fission products, the refuelling programme should meet the following objectives throughout the lifetime of the reactor, starting from the initial fuel loading:

(a) Maintaining neutron flux distribution and other core parameters within the applicable operational limits and conditions;
(b) Maintaining an adequate shutdown margin.

2.66. Considerations for the establishment and use of a refuelling programme include the following, as appropriate:

(a) Fuel burnup and consequent structural and metallurgical limitations;
(b) Temperatures of coolant and fuel cladding in relation to flux distributions, channel flows and absorber configurations;
(c) Increase in power output from a fuel assembly, either during on-load refuelling or while the reactor power is being raised (this might impose a restriction on the rate of rise of reactor power, or there might need to be a minimum time for holding the power constant before the next power increment);
(d) Avoidance of unacceptable flux tilts and reactor instability;
(e) Assurance of the mechanical capability of fuel elements to withstand reactor core conditions and refuelling operations, particularly for shuffling and reuse of irradiated fuel elements;
(f) Availability and capability of refuelling machines (for reactors designed for on-load refuelling);

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[8] Some reactors using natural uranium show a reactivity increase as plutonium builds up in the fuel during its early use. The same applies for fuels bearing burnable absorbers such as gadolinium.

(g) Special considerations for particular fuel assemblies, which might necessitate restrictions such as limitations on the power output;
(h) Changes arising from the removal of failed fuel and the insertion of fresh fuel assemblies (such as changes in local temperatures and changes in reactivity);
(i) Selection of channels for on-load refuelling to maintain radial symmetry and, in the case of bidirectional refuelling, axial symmetry;
(j) Positioning of unirradiated and irradiated fuel in the core, with enrichment levels and neutron absorber levels being taken into account;
(k) Depletion of neutron absorbers in control rods and of burnable absorbers;
(l) The highest reactivity worth of an individual control rod that could remain inoperable in the fully withdrawn position;
(m) Deviations of actual core operating parameters from the calculated values used in the refuelling programme (these necessitate consideration of control rod and absorber configurations, fuel burnup, neutron flux distribution and depletion of neutron absorbers);
(n) Changes due to thermal shock, and changes in reactivity during on-load refuelling;
(o) Changes in the radiation characteristics of fuel assemblies, absorbing rods and neutron sources after irradiation in the reactor core.

2.67. After off-load refuelling of a reactor, the core conditions should be assessed before startup to verify that the operational limits and conditions and shutdown margins will be met throughout the time that the fuel will be in the core. Shutdown capability should be confirmed by appropriate testing.

2.68. For reactors that are refuelled on load, the criteria governing the refuelling programme should be set out and compliance with all applicable operational limits and conditions should be verified. If there are significant deviations from the established fuelling programme, a safety assessment of the new core conditions should be made, and any necessary actions should be taken.

2.69. The predictions of core behaviour needed for the assessments described in paras 2.67 and 2.68 are discussed in paras 2.5–2.12. Calculations based on simulations with current reactor data should be used to update assessments of core performance and to plan the subsequent refuelling programme. Other data (e.g. on fuel burnup rates, reactivity, power density and neutron flux distributions) should also be obtained in such simulations.

2.70. For reactors that are refuelled on load, information on fuel scheduling, including a list of channels containing fuel and the corresponding burnup, should be available. The selection of channels for refuelling should take into account this information and other considerations, including those listed in para. 2.66.

2.71. In reactors that are refuelled off load, it is normal to have control rods in the core during startup, during load changes and at steady power. The refuelling programme should specify the control rod patterns and sequencing that will ensure compliance with the design intent for control rod reactivity worths and power distribution.

2.72. Checks are required to be performed after refuelling to provide assurance that the core has been correctly configured; see para. 7.19 of SSR-2/2 (Rev. 1) [1]. In addition, physics tests should be performed before or during startup after each refuelling to verify the constitution and characteristics of the core and control rod reactivity worths and boron worths throughout their operating range. Tests should include the following, as appropriate:

(a) Withdrawal and insertion of each control rod to check for operability;
(b) Control rod drop times (pressurized water reactors) or hydraulic insertion times (boiling water reactors);
(c) Integral and differential, or dynamic, rod worth measurement;
(d) Demonstration that, if the control rod with the strongest worth is in the fully withdrawn position, the core meets the specification for shutdown margins;
(e) Comparison of predicted and measured critical rod configurations for non-voided conditions in accordance with planned rod withdrawal sequences;
(f) Measurement and assessment of the moderator temperature coefficient and other temperature coefficients of reactivity, of critical boron concentrations and of rod bank worths;
(g) In-core flux mapping and core symmetry checks using either symmetrical control rods or in-core instrumentation;
(h) Comparison of measured and calculated flux distributions and power distributions (axial and radial);
(i) Confirmation of core power symmetry by checking for mismatches between measurements.

The test results should be reviewed independently by competent persons with suitable expertise in reactor physics.

SURVEILLANCE RELATING TO CORE MANAGEMENT AND FUEL HANDLING

2.73. A core management and fuel handling surveillance programme should be established for the early detection of any deterioration that could result in an unsafe condition in the reactor core. Surveillance activities should include monitoring, checking, calibration, testing and inspection. These activities should be part of an overall surveillance programme to be formulated and implemented in accordance with the recommendations provided in SSG-74 [6]. The following items that are particularly relevant to core management and fuel handling should be included in the surveillance programme:

(a) Protection and control systems (i.e. operability, actuation times and reactivity change rates);
(b) Instrumentation for monitoring core parameters (see para. 2.37);
(c) Core cooling systems, including the cooling of core components (i.e. flow rate, pressure, temperature, activity and chemistry of the coolant);
(d) Handling systems for fuel and core components (including instrument and interlock checks);
(e) Degradation of fuel and other core components, such as bowing effects of fuel assemblies and fretting, oxidation of cladding, crud deposition, wear-out and swelling of control rods.

2.74. The equipment qualification programme at the plant (see SSG-69 [13]) should confirm the capability of the instrumentation and systems used for core monitoring, fuel handling and storage to perform their functions, for the relevant time period under given environmental conditions (e.g. conditions of pressure, temperature, radiation levels, mechanical loading and vibration), taking into account the appropriate functional and safety issues.

3. HANDLING AND STORAGE OF FRESH FUEL

MANAGEMENT OF FRESH FUEL

3.1. The main safety objectives of a fresh fuel handling programme are to prevent an inadvertent criticality and to prevent damage to the fuel when it is being moved, stored or manipulated. Nuclear fuel should be protected against any damage, in particular damage that could be expected to affect its behaviour in the core.

3.2. The principal elements of a fresh fuel handling programme include receipt, transfer, inspection and storage of the fuel. The programme should be based on a methodical approach that is controlled by procedures and engineering practices. The main purposes of this programme are as follows:

(a) To delineate physical boundaries within which fresh fuel is to be stored and which are subject to material control procedures and constraints on the criticality configuration;
(b) To meet requirements and to provide technical instructions for fresh fuel inspections, including contingency actions for dealing with damaged fuel.

3.3. Proper facilities for the receipt, storage and handling of a full consignment of fuel should be available on the site before any fresh fuel is delivered to the site. If fuel of a new design is to be delivered, or if the fuel enrichment has changed or re-racking of a storage area is necessary, the validity of the criticality safety analysis should be reassessed before receipt of the fuel. Recommendations on the design of such facilities, including consideration of events that could lead to inadvertent criticality excursions or could adversely affect the fuel and/or fuel handling and storage systems, are provided in IAEA Safety Standards Series No. SSG-63, Design of Fuel Handling and Storage Systems for Nuclear Power Plants [15].

3.4. Before the first fuel is delivered to the site, the relevant parts of the radiation protection programme (see IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [16]) should be implemented. In addition, adequate emergency preparedness and response arrangements are required to have been implemented and tested, in accordance with the requirements established in IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [17], and Requirement 18 of SSR-2/2 (Rev. 1) [1].

3.5. Fresh fuel containing reprocessed materials, which produces a higher radiation level and higher heat generation compared with fresh UO_2 fuel, should be handled in accordance with procedures designed specifically to reduce doses to operating personnel. Shielding measures should be taken, as appropriate, to ensure that occupational exposures are as low as reasonably achievable, in accordance with Requirement 11 of GSR Part 3 [14].

3.6. Fuel handling procedures should, in particular, underline the need to minimize mechanical stresses, particularly lateral stresses, with emphasis on those cases where small stresses might be harmful to fuel assemblies. The magnitudes and directions of any forces and accelerations applied to the fuel assemblies should be maintained within design limits.

3.7. To reduce the possibility of causing damage to fuel during handling, only equipment designed for handling the fuel should be used.

3.8. Personnel engaged in handling fuel should be suitably qualified and trained, and are required to work under the supervision of an authorized person (see para. 7.28 of SSR-2/2 (Rev. 1) [1]). All activities relating to the fresh fuel should be performed in accordance with approved procedures. Key steps in such activities should be verified and signed off by authorized personnel.

3.9. When fuel is handled manually, suitable protective equipment and clothing should be used to prevent contamination of personnel and to prevent damage to or contamination of the fuel cladding. Requirements for the protection of workers are established in GSR Part 3 [14], and recommendations are provided in GSG-7 [16].

3.10. If fuel is to be moved between buildings on the site, suitable and appropriately labelled casks and packages should be used to prevent contamination of or damage to the fuel. The routes for all fuel movements should be kept as short and simple as possible.

3.11. The areas for the handling and storage of fresh fuel should be maintained under appropriate environmental conditions (in respect of humidity, temperature and clean air) and controlled at all times to exclude chemical contaminants and foreign materials.

3.12. Access to fuel storage areas is required to be limited to authorized personnel (see para. 7.28 of SSR-2/2 (Rev. 1) [1]). The handling and storage areas for fresh fuel should be secured against unauthorized access and unauthorized removal of fuel. A storage area should not be part of an access route to other operating areas. Further guidance on nuclear security is provided in Ref. [18].

3.13. Heavy loads should not be moved above stored fresh fuel (in racks, storage canisters, packages or lifting devices). Any exceptions to this should be justified.

3.14. The equipment used to check the physical dimensions of the fuel should be periodically recalibrated. Fuel handling equipment and associated systems should be checked periodically (or at least before a refuelling campaign) and maintained in good operational condition.

3.15. Emergency operating procedures and associated equipment should be provided to ensure that fuel assemblies can be readily placed in a safe location under all circumstances.

RECEIPT OF FRESH FUEL

3.16. Before fuel is received, the operating organization should make arrangements to ensure that a designated person is responsible for the control of the fuel on the site.

3.17. Fuel should be received, unpacked and inspected by trained and qualified personnel in accordance with written procedures for the identification of damaged fuel or any other non-conformances. The receipt and unpacking of fresh fuel should take place in an area that is designed for fuel handling. An inspection programme for fresh fuel should be established to check the external appearance of the fuel and to check for any damage that has occurred during transport. Inspection of the fuel should include the checking of specified parameters (such as dimensions) that might have been affected by transport and handling since the final inspection by the supplier. The identification number of each fuel assembly should be verified, and related documentation should be checked to confirm that the fuel received corresponds to what was ordered and conforms to design requirements.

3.18. The procedures for the identification of damage and any other non-conformance in the fuel should be reviewed if fuel of a new design or a modified design is to be brought onto the site. Acceptance criteria should be available for use in assessing whether fuel is damaged. A record should be made of any damage accepted by the personnel inspecting the fuel. Rejected fuel should be treated as a non-conforming product (see paras 6.50–6.77 of GS-G-3.1 [12]). The root causes of any failures should be investigated, and corrective measures should be taken to prevent their recurrence.

3.19. Transport packages should be checked to verify that they are properly identified and free from damage. Storage arrangements and identification should be such as to eliminate unnecessary handling.

3.20. Fresh fuel should be free of foreign material before use at the plant. Inspections at the plant should be capable of identifying any foreign material already present in the fuel. Such inspections should not introduce any foreign material into the fuel.

3.21. If fresh fuel assemblies have to be repaired, the fuel supplier should be involved in any proposed repair or modification. Technical and administrative precautions should be taken to ensure that only the specified fuel assemblies are repaired, that the repair work is carried out in accordance with written instructions (e.g. relating to the position, enrichment and poison content of the fuel elements), and that a critical configuration is not created.

3.22. Any fuel suspected of being damaged during handling or storage should be subject to additional inspections and, if necessary, treated in accordance with the procedures for dealing with damaged fuel.

STORAGE OF FRESH FUEL

3.23. Adequate and specified storage positions should be available to ensure the integrity of fuel assemblies and to prevent them from being damaged. In particular, appropriate measures should be taken to avoid axial twisting of the fuel assemblies.

3.24. The storage area for fresh fuel should be operated so as to ensure that the subcriticality criteria specified in the design (see SSG-63 [15]) are met. Subcriticality should be maintained at all times, even in the event of internal or external flooding or any other event considered in the design. Physical and/or administrative measures should be taken to ensure that fuel is handled and stored only in approved locations in order to prevent a critical configuration from arising. It should be verified that the enrichment of the fuel is commensurate with the design limitations of the storage area.

3.25. A dry fresh fuel storage area should be clear of any equipment, valves or piping that undergo periodic surveillance by operating personnel.

3.26. For a wet fresh fuel storage area, the water conditions and rack layout should be maintained within specified operational limits to ensure the subcriticality margins. Requirements for water chemistry (see paras 7.13–7.17 of SSR-2/2 (Rev. 1) [1]) should be strictly observed, in order to minimize the corrosion of the fuel cladding and the storage components (see also para. 5.15).

3.27. For fresh fuel storage systems that use neutron absorbers, a lifetime surveillance programme should be put in place to ensure that the absorbers are installed and that they have not lost their effectiveness or been displaced.

3.28. When fuel assemblies are stored outside their sealed transport packages, a suitable ventilation system should be used to prevent dust and other airborne particles from entering the fresh fuel storage area. One way to achieve this is to use filters in the inlet air channel and to keep the ambient air pressure of the storage area slightly higher than that of the surrounding areas.

3.29. Drains in dry storage areas for fresh fuel should be kept unobstructed to ensure the efficient removal of any water that might enter and to ensure that poor drainage does not become a possible cause of flooding.

3.30. Fire risks in the fresh fuel store should be minimized by preventing the accumulation of combustible material in the storage area. Instructions for firefighting and firefighting equipment suitable for use in case of fires involving fuel should be readily available. Procedures should be established for controlling the transfer of moderating material into the fresh fuel storage area to ensure that subcriticality will always be maintained, even if fire extinguishing materials are used. Further recommendations on fire safety are provided in IAEA Safety Standards Series No. SSG-77, Protection Against Internal and External Hazards in the Operation of Nuclear Power Plants [19].

3.31. Unauthorized access to fresh fuel should be prevented from the time of its arrival on the site. Any fresh fuel storage area should be designated as an area where only fuel handling activities should take place.

4. IMPLEMENTATION OF THE REFUELLING PROGRAMME

PREPARATION FOR REFUELLING

4.1. The refuelling programme described in paras 2.62–2.72 should be implemented by means of a refuelling plan that specifies in detail the sequence of the operations to be carried out. The refuelling plan should specify the types of fuel and core components to be withdrawn from the storage areas, the route they are to take and the positions they are to occupy in the core. The plan should also specify the following:

(a) Which fuel is to be shuffled or unloaded, and its original position in the core;

(b) The new location for the fuel, either in the core or in the storage areas;
(c) The sequence for unloading and loading fuel and core components such as control rods;
(d) The checks to be performed at each step.

4.2. The steps necessary to assemble fresh fuel and to prepare it for use in the reactor, including any arrangements for holding it in intermediate storage, should be specified in the refuelling plan. Only fuel that meets the requirements established in para. 7.18 of SSR-2/2 (Rev. 1) [1] may be loaded into the reactor core. Checks should be carried out to confirm that the fuel has been assembled correctly. In all fuel handling and maintenance activities, it should be ensured as far as possible that no foreign material is introduced into the reactor (see paras 4.25–4.27).

4.3. Reliable means of two-way communication between the fuel handling personnel and the control room personnel should be available at all times.

LOADING FUEL AND CORE COMPONENTS INTO THE REACTOR

4.4. When fuel is moved from storage, it should be identified and checked against the approved refuelling plan. Arrangements should be made to ensure that the fuel has been loaded into the specified position in the core and correctly positioned (and, in the case of light water reactors, with the specified orientation). These arrangements should include an independent check by personnel not directly involved in the loading operation. Any subcriticality checks to be performed during off-load refuelling should be specified in the refuelling plan.

4.5. Although handling procedures may be simpler when a reactor is being loaded for the first time (i.e. because the fuel and core components have not yet been irradiated), the refuelling plan and the quality management programme should still be followed. Checks should be carried out before fresh fuel is loaded into the refuelling machine or the core, to ensure that all equipment, materials and dummy or test fuel assemblies used for commissioning have been removed. Precautions should also be taken to prevent foreign materials from entering the reactor core (see paras 4.25–4.27). Dummy or test fuel assemblies should be clearly distinguishable, even when in the core. Procedures should be followed to ensure that all unnecessary material has been removed from the reactor vessel before it is closed. Further recommendations on the first loading of fuel are provided in IAEA Safety Standards Series No. SSG-28, Commissioning for Nuclear Power Plants [20].

4.6. Procedures should be established to test the fuel transfer machine and any other tool or system that might be necessary, before the commencement of fuel loading.

4.7. The personnel involved in fuel loading should be qualified and trained. Refuelling machine operators should be licensed in accordance with regulatory requirements (see para. 4.16 of SSR-2/2 (Rev. 1) [1]). Personnel should be trained in the correct use of the fuel transfer machine, initially using dummy fuel, including operations over the entire route travelled by fuel, from the reception point to the reactor cavity and the spent fuel pool.

4.8. Any core component (e.g. instrumentation, coolant flow orifice plate, plug, control rod, neutron absorber) that forms part of or is attached to a fuel assembly should be inspected and checked as part of the refuelling procedure, in accordance with the quality management programme for the plant. All safety aspects relating to neutron source assemblies and core components should be considered before these assemblies and components are loaded into the reactor core.

4.9. Procedures should be established for controlling the movement of core components into or out of the core. Checks should be performed, where possible, to ensure satisfactory insertion of the fuel. For an item that is not part of the design as described in the safety analysis report and is not a permanent part of the plant (such as samples of materials to be irradiated), the procedures should involve a thorough safety review of the item and appropriate approval for its movements into and out of the core, and for its residence within the core.

4.10. When a significant quantity of fuel is being loaded into a shutdown reactor, the subcritical count rate should be monitored to prevent an unanticipated reduction in the shutdown margin or an inadvertent criticality. Shutdown margin verification tests should be performed on the fully loaded core.

4.11. For on-load refuelling, the integrity of the reactor pressure boundary for heat transport should be maintained at all times while at power. During the transfer of fuel across the containment boundary, provision should be made to ensure the integrity of the containment at all times.

UNLOADING FUEL AND CORE COMPONENTS

4.12. Measures should be taken to verify that a fuel assembly does not hang from the upper core support structure while this structure is lifted prior to unloading the core.

4.13. Fuel should be unloaded in accordance with a refuelling plan.

4.14. The identification of the fuel assemblies or core components should be checked against the refuelling plan whenever practicable, either during or following fuel unloading from the core. Any error found, either in the original loading or in the unloading, should be reported and a review undertaken by the plant management to ensure that appropriate action is taken.

4.15. Only suitable designated areas should be used for storing (even temporarily) irradiated or contaminated items to avoid the spread of contamination and/or unnecessary radiation exposure.

4.16. If conditions warrant it, and if any physical damage is suspected, unloaded fuel and core components should be examined before storage. If fuel or core components are found to be damaged, adjacent components should be examined. Any repairs should, ideally, be based on proven techniques and carried out in accordance with an approved method.

4.17. Any fuel that is known to have failed should be treated in such a way as to minimize contamination of the storage facility and to enable compliance with the applicable requirements for transport off the site (see IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [21]). Any fuel that is suspected to have failed should be treated as failed fuel until a thorough check shows that it is intact.

4.18. Before the rack locations in the storage facility receive unloaded fuel, they should be examined if it is suspected that there could be damage that could affect the integrity of the fuel or if the allocated rack already contains a fuel assembly or any core component, such as control rods. Racks should be kept within specified vertical tolerances to ensure that fuel assemblies are not distorted.

PRECAUTIONS FOR LOADING AND UNLOADING FUEL AND CORE COMPONENTS

4.19. By means of appropriate handling and storage of fuel, it should be ensured that fuel integrity is preserved at all times. The condition of the fuel should be checked prior to its use in order to minimize the risk of inserting damaged fuel into the reactor.

4.20. The procedures for the implementation of the refuelling plan should include the necessary precautions to ensure safety. Aspects such as reactivity status, component integrity, heat dissipation and radiation protection (including the use of shielding) should be considered. The issues to be considered during fuel handling and the handling of core components include the following:

(a) Criticality safety, for example from errors when manipulating reactivity control devices;
(b) Physical damage to fuel resulting from bumping or dropping of components;
(c) Damage to fuel due to distortion, swelling or bowing of fuel assemblies or fuel elements;
(d) Occupational exposure due to the radioactivity of components or radioactive material released during handling.

4.21. For reactors that are refuelled off-load, the prerequisites for ensuring that a critical configuration is not formed during fuel loading, such as nuclear startup instrumentation and protection system interlocks, should be checked before and, as appropriate, during the loading process. This is particularly important during the first core loading. This is also applicable to the shutdown period after maintenance for reactors that are refuelled on-load. Further recommendations on these prerequisites are provided in SSG-28 [20].

4.22. The overriding of automatic safety systems (such as overload or alignment interlocks) should be prohibited in normal handling procedures for both fresh fuel and for irradiated fuel. Under abnormal fuel handling conditions, an urgent need to override interlocks might arise. Such actions should only be carried out by competent and authorized personnel, in accordance with approved procedures. An independent safety review of such actions should be performed before they are implemented.

4.23. The following are examples of specific issues that should be taken into consideration with regard to refuelling operations with the reactor core shut down[9]:

(a) Measures for radiation protection and supervision during the refuelling process should be established.
(b) Containment or confinement integrity should be as specified for refuelling.
(c) Air cleaning systems should be operable as specified.
(d) A reliable power source should be available.
(e) Startup range neutron flux detectors or any other detectors specifically used for refuelling and related alarms should be operable.
(f) Control rods should be inserted into the core and disconnected to render them inoperable. In pressurized water reactors, borated water with the specified boron concentration should be circulated, and positive measures should be taken to prevent dilution (e.g. lockout of pure water control valve, locking of all borated water systems likely to be used in the vicinity of the reactor).
(g) The reactor vessel and pool storage water levels should be maintained above specified minimum levels.
(h) The reactor should be subcritical for a minimum specified period and by a minimum amount before fuel unloading is commenced.
(i) Appropriate interlocks should be in the correct configuration, and the necessary functional checks and calibrations should be carried out on the control rod drive circuit, the reactor protection system and the refuelling equipment.
(j) An adequate number of shutdown cooling loops (at least one) should be in operation with appropriate emergency cooling capability available.
(k) Appropriate procedures should be established to prevent foreign materials from being introduced into the reactor vessel (see paras 4.25–4.27).
(l) Measures should be taken to prevent any unnecessary handling of components or tools over the reactor pool while handling a fuel assembly.
(m) Adequate communication links should be established between the control room and the fuel loading area. An authorized person should be in charge throughout the entire refuelling process.
(n) A final check should be carried out before vessel closure to ensure that the core has been correctly loaded (checking fuel and core component identification) and, if possible, a video recording should be made for subsequent verification.

[9] The list takes into account the considerations for a light water reactor design. Similar lists may be prepared for other types of reactor that are also refuelled in a shutdown condition.

(o) Emergency operating procedures should be provided to specify the actions to be taken in the event of incidents during fuel handling.

4.24. For reactors that are refuelled on-load, the following issues should be taken into consideration:

(a) Reactor operating conditions should be established and should be stable at the level pertaining to the refuelling.
(b) All monitoring instrumentation and safety devices necessary for safe and correct refuelling should be calibrated and confirmed to be in service and operating satisfactorily.
(c) It should be confirmed that the correct fuel assemblies are collected from the right storage locations and loaded into the appropriate magazine of the refuelling machine, and space should be available in the magazine to receive the unloaded fuel.
(d) Commencement of refuelling should be authorized by control room operators, who should be kept informed of the state of refuelling.
(e) Independent checks should be made to ensure that the refuelling machine is properly connected to the correct fuel changing location. For bidirectional refuelling designs, it should be ensured that both the loading and the unloading machines are aligned on the same channel before clamping.
(f) In the refuelling machine, alternative means of plugging the reactor channel should be available if the new fuel assembly cannot be used.
(g) The refuelling machine should be capable of penetrating and reinstating the reactor containment boundary.
(h) Before disconnecting the refuelling machine from the fuel channel, it should be confirmed that the closure plug has been properly replaced.
(i) Satisfactory replacement of the closure plug should be checked before significant coolant pressure is established after refuelling in the depressurized state.
(j) Administrative controls should be in place to supplement design provisions against movement of the refuelling machine while it is connected to the reactor.
(k) Controls should be established to ensure that irradiated fuel in the refuelling machine is properly discharged before the coolant supply to the machine is stopped and to prevent, where appropriate, movement of the machine outside its design range.
(l) Strict adherence to procedures should be ensured by techniques such as automatic control and/or use of checklists.
(m) The refuelling machine should be capable of accessing an area for maintenance when the reactor is operating.

(n) Facilities should be provided for testing the refuelling machine under conditions as representative of actual operation as possible.
(o) Emergency operating procedures should be in place to specify the actions to be taken in the event of incidents during fuel handling.

FOREIGN MATERIAL EXCLUSION ARRANGEMENTS FOR FUEL HANDLING

4.25. The foreign material exclusion programme at the plant should include provisions to prevent the intrusion of foreign materials during specific activities close to the fuel or fuel-containing facilities, in order to prevent fuel damage or loss of integrity (immediate or latent). Specific attention should be paid to maintenance activities, in particular during outages, on the opened main cooling circuit systems and components, on the reactor vessel cavity and on spent fuel storage facilities. Appropriate arrangements for foreign material exclusion should be established and maintained for all operations with fresh and irradiated fuel. Fresh fuel should be inspected in accordance with the plant procedures to ensure that foreign material is not present.

4.26. The specific zone for foreign material exclusion should be established around the places where fuel handling activities are planned. This zone should be appropriately labelled and demarcated by stanchions or barriers. A buffer zone should be designated by markings on the floor around the foreign material exclusion zone to minimize the potential for intrusion of foreign material. The storage of tools, equipment or materials within the buffer zone should be minimized.

4.27. The necessary clean working conditions should be created at places where fuel handling or fuel repair operations are in progress, to prevent foreign material from entering any opened cavities. This should be accomplished by taking only necessary materials into the foreign material exclusion zone, maintaining positive control of all such materials, and then removing them from the area as soon as possible. An ‘empty pockets’ policy[10] should be implemented for work in close proximity to the spent fuel pool or open reactor vessel cavity. All materials and tools entering the foreign material exclusion zone should be logged in and out using a tool and material control log. All items and materials should be removed from the foreign material exclusion zones at the end of each shift, unless doing otherwise has been approved and documented. Activities that could generate

[10] An ‘empty pockets’ policy specifies that loose objects in pockets should be removed before entering the zone or that pockets should be adequately secured.

debris should be avoided as much as possible within foreign material exclusion zones. Where these activities cannot be avoided, appropriate arrangements should be made to capture any debris generated.

5. HANDLING, STORAGE AND INSPECTION OF IRRADIATED FUEL

GENERAL

5.1. The main safety objectives associated with the handling and storage of irradiated fuel are as follows:

(a) To ensure subcriticality at all times;
(b) To prevent physical damage to fuel assemblies and/or to the fuel elements;
(c) To ensure an adequate rate of removal of heat;
(d) To ensure that radiation exposures and the release of radioactive substances during the handling of irradiated fuel are kept as low as reasonably achievable.

5.2. To ensure that fuel integrity and subcriticality are maintained, irradiated fuel should be handled, stored and inspected only in approved facilities and with equipment that has been qualified for this purpose (see SSG-69 [13] and SSG-63 [15]). All handling, movement and storage of irradiated fuel and core components is required to be undertaken in accordance with written procedures (see paras 7.26 and 7.28 of SSR-2/2 (Rev. 1) [1]).

5.3. Appropriate emergency operating procedures and severe accident management guidelines are required to be established to manage events and accidents during the handling and storage of irradiated fuel (see Requirement 19 of SSR-2/2 (Rev. 1) [1]). These procedures and guidelines should cover events arising within the plant (e.g. criticality, loss of heat removal, dropped loads, internal fires and floods, human errors, failures of safety related systems) and those events external to the plant (e.g. seismic events, flooding, high winds and tornadoes, loss of off-site electrical power, a combination of related events). Recommendations relevant to accidents that might occur in fuel handling and storage are provided in SSG-63 [15] and in IAEA Safety Standards Series No. SSG-15 (Rev. 1), Storage of Spent Nuclear Fuel [22]. Recommendations on the development and implementation of emergency operating procedures and severe accident management guidelines during all modes of operation for the reactor, the spent fuel pool and or any other fuel location are provided in IAEA Safety Standards Series No. SSG-54, Accident Management Programmes for Nuclear Power Plants [23].

HANDLING OF IRRADIATED FUEL

5.4. A system should be in place to account for the nuclide inventory and the decay heat of the irradiated fuel.

5.5. Before handling irradiated fuel, the operability of all fuel handling and transfer equipment and the associated safety features should be confirmed. This equipment should include the following:

(a) Fuel handling machines;
(b) Fuel transfer equipment;
(c) Fuel lifting devices;
(d) Means of assembling, disassembling and repairing fuel;
(e) Handling devices for all operations associated with transport of casks or inspection of spent fuel or casks;
(f) Equipment for the safe handling of degraded or failed fuel or casks;
(g) Load measurement devices, including overload protection;
(h) Illumination equipment;
(i) Appropriate shielding;
(j) Radiation protection equipment;
(k) Decontamination equipment;
(l) Instrumentation and control systems;
(m) Communication equipment;
(n) Fuel inspection equipment;
(o) Relevant ventilation and filtering systems.

5.6. Residual heat from irradiated fuel should be removed at a rate sufficient to prevent unacceptable degradation of the fuel assembly and of the storage and support systems. The increased evaporation rate of pool water should be taken into account.

5.7. The spread of contamination should be controlled and minimized. Dedicated equipment and procedures should be provided for dealing with leaking fuel.

5.8. Shielding should be provided around all areas in which irradiated fuel or activated core components may be placed. This is necessary to ensure that occupational exposure to external radiation from fission products and activated materials is kept as low as reasonably achievable, in accordance with Requirement 11 of GSR Part 3 [14].

5.9. Coolant chemistry is required to be controlled (see Requirement 29 of SSR-2/2 (Rev. 1) [1]), in order to maintain the integrity of fuel and to ensure subcriticality.

5.10. Special, non-routine activities relating to irradiated fuel (e.g. fuel cleaning, crud removal, recovery of damaged fuel, application of special fuel inspection stands) should be carefully planned and implemented in accordance with established procedures. A specific safety review is required to be performed (see para. 4.27 of SSR-2/2 (Rev. 1) [1]), and this should be reviewed independently. Operating procedures and emergency operating procedures are required to be prepared, and operating personnel are required to be suitably trained (see Requirement 26 and para. 4.17 of SSR-2/2 (Rev. 1) [1]). The roles and responsibilities for the implementation and supervision of non-routine activities should be established, and continuous radiation monitoring should be provided. Such activities should be carried out such that the fundamental safety functions of subcriticality, residual heat removal and confinement of radioactivity (see Requirement 4 of SSR-2/1 (Rev. 1) [2]) are always maintained and radiation protection rules are fully observed.

STORAGE OF IRRADIATED FUEL

5.11. Adequate and specified storage areas should be used for the storage of irradiated fuel. Procedures should be established and implemented to ensure that the irradiated fuel is stored only in fully assessed configurations. Fuel storage analyses should consider, for example, new fuel designs, extended burnups and storage configurations for new fuel. Further recommendations are provided in SSG-15 (Rev. 1) [22].

5.12. In addition to ensuring the use of approved configurations, conformance with the criteria for neutron absorbers in the storage facility and, where appropriate, with the maximum capacity is also necessary. Specified neutron absorbers should be fixed absorbers or, for pool storage, complemented by boron in the water. A surveillance programme should be in place to ensure the integrity of the neutron absorbers. Suitable quality management procedures should be implemented to ensure subcriticality.

5.13. Reliable removal of residual heat should be ensured to prevent unacceptable degradation of the fuel assemblies. It should be ensured that the bulk temperature of the pool water, as well as variations and rates of change of temperature, are maintained within acceptable limits, as specified in the design requirements (see SSG-15 (Rev. 1) [22]).

5.14. For wet storage facilities for irradiated fuel, the composition of the cooling medium should be controlled to prevent deterioration of the fuel cladding for all postulated conditions of irradiated fuel. For dry storage facilities, it should be ensured that there are no impairments (i.e. blockages or perturbations) to the flow of the cooling medium. If heat removal is provided by natural or forced circulation, sufficient reliability of the heating, ventilation and air-conditioning systems should be ensured.

5.15. For wet storage, water conditions should be maintained in accordance with specified values of temperature, pH, oxidation reduction reaction (redox), radioactivity and other applicable chemical and physical characteristics, so as to achieve the following:

(a) To prevent the corrosion of fuel, core components and structures in the pool by maintaining suitable pH values and other applicable chemical conditions;
(b) To prevent boron crystallization by maintaining pool temperatures above a minimum level;
(c) To reduce contamination and radiation levels in the pool area by limiting water evaporation and taking measures to remove radioactivity from the water;
(d) To facilitate fuel handling in the pool by maintaining water clarity (i.e. by removing impurities and suspended particles) and providing adequate underwater illumination;
(e) To prevent boron dilution in pools in which soluble boron is used for criticality control.

5.16. To avoid damage to fuel in the storage pool, the movement of heavy objects (i.e. objects that are not part of the lifting devices) above stored fuel should be prohibited unless specifically authorized on a case by case basis, on the basis of a detailed safety analysis. All lifting should be restricted to the minimum height necessary to complete the operation safely. The pool crane should be checked prior to the start of fuel handling to ensure correct operation.

5.17. Storage areas should be kept under surveillance for radiation protection purposes. Examples of the precautions that should be taken to optimize radiation exposures for wet storage include the following:

(a) The pool water level should be maintained between specified levels, leakage should be monitored, and water level alarms should be tested.
(b) Radiation monitors should be checked for operability and correct adjustment to ensure that the alarm settings are correctly set.
(c) Radiation levels at the water surface should be limited by the use of approved procedures and tools that ensure that fuel is not raised too close to the water surface.
(d) The ventilation system should be operated correctly to ensure that levels of airborne contamination remain within limits.
(e) Adequate communications should be provided between the pool area, the control room and radiation protection personnel.
(f) There should be proper supervision and work control procedures (with the use of radiation work permits, as appropriate (see paras 3.94–3.96 of GSG-7 [16])). Adequate training in radiation protection is required to be provided (see Requirement 26 of GSR Part 3 [14]). Records of occupational exposure and of workers' health surveillance are required to be kept (see Requirement 25 of GSR Part 3 [14]).
(g) The fuel pool area should be designated as a controlled area, in accordance with paras 3.88–3.90 of GSR Part 3 [14].

5.18. For some reactor types, it is important for safety purposes to retain sufficient capacity in the irradiated fuel storage facility to accommodate the fuel inventory of the reactor and one full set of control rods at any given time.

5.19. A policy for the exclusion of foreign materials (see paras 4.25–4.27) should be adopted for all storage of irradiated fuel. Procedures should be in place to control the use of materials that cannot be seen in water (e.g. transparent sheets) and loose parts.

5.20. Plans should be prepared for dealing with damaged or leaking fuel assemblies, and appropriate storage arrangements should be made for them, such as the following:

(a) Storing leaking or damaged assemblies separately from other irradiated fuel, if the safety analysis does not allow them to be stored together;

(b) Providing containers (together with space to store them) capable of retaining a severely damaged assembly and any fragments, while still providing adequate cooling;
(c) Providing containers or quivers for failed rods removed from assemblies that function as a new first barrier and can be used either for long term storage or for transport off the site.

INSPECTION OF IRRADIATED FUEL

5.21. In order to monitor the performance of fuel elements in the core and to predict their further behaviour, a programme for inspection of the irradiated fuel should be established and implemented. This is especially important when the unloaded fuel is to be reused in subsequent cycles. The results of inspection are also important in ensuring the integrity of the fuel when it is finally dispatched from the site, and in investigating the root causes of leaking fuel and providing feedback to the fuel supplier. This programme could include the following:

(a) Selection of fuel assemblies to be examined periodically throughout their residence in the core and in storage as irradiated fuel (consideration may also be given to including some assemblies for post-irradiation examination);
(b) Use of lead test assemblies for testing new fuel designs and for increasing burnup, and a follow-up inspection programme for such fuel (using hot cells) to study structural behaviour;
(c) Arrangements for feedback and exchange of information with the fuel supplier.

5.22. Inspections should be performed in appropriate locations, using equipment and procedures designed for the purpose, and the results should be recorded. Appropriate space should be provided to carry out the inspection, identification, dismantling and reconstitution of fuel, as necessary. Appropriate means should be implemented to prevent excessive heating of a fuel assembly in a sipping test container (used for irradiated fuel examination), including in case of an incident (e.g. loss of electric power, blockage of the closure head of container).

6. HANDLING AND STORAGE OF CORE COMPONENTS

6.1. The aspects that should be considered in the handling and storage of unirradiated components include the prevention of physical damage, assurance of cleanness and prevention of radioactive contamination.

6.2. Adequate specified storage positions should be used for the storage of core components, particularly irradiated core components. This applies to all types of reactivity control devices and shutdown devices, neutron sources, dummy fuel, fuel channels, instrumentation, flow restrictors, burnable absorbers, samples of reactor vessel material, other core components and other items such as storage containers and transport packages.

6.3. All new core components should be visually examined for physical damage before insertion into the core. Where appropriate, dimensional and functional checks should be made to ensure that the components are in a proper state for their intended use.

6.4. Each core component should be adequately identified, and a record should be kept of its location and orientation within the core, its out-of-core storage position and other pertinent information so that an irradiation history of the component is available.

6.5. Core components can become highly radioactive during reactor operation. For irradiated core components, the following measures should be considered:

(a) Irradiated core components should be stored only in special locations in the storage area designed for the purpose, and care should be taken not to store irradiated core components in the area used for fresh fuel or in other clean storage areas.
(b) Adequate cooling should be provided.
(c) Access should be limited, and shielding should be provided, as appropriate, for radiation protection purposes.
(d) The materials of the core component and the storage medium should be compatible.
(e) Any component that is to be reused or that needs to be retrieved for other reasons should be accessible.
(f) Where inspection of irradiated components is necessary, interlocks should be provided and other appropriate measures should be taken to ensure that

occupational exposure is as low as reasonably achievable, in accordance with Requirement 11 of GSR Part 3 [14].

(g) Means of transferring irradiated components into a suitable transport package should be provided, where necessary.

6.6. An appropriate space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of core components, without reducing the storage capacity for core components. Adequate space for the receipt of other core components might also be necessary.

6.7. Neutron sources should be shielded and should be handled appropriately. Such sources are required to be managed in accordance with Requirement 17 of GSR Part 3 [14]. This includes the clear identification of all sources and procedures for controlling the use of these sources. Contamination checks should be performed following the receipt of transport packages containing neutron sources. The transport packages for neutron sources are required to be clearly marked in accordance with SSR-6 (Rev. 1) [21].

6.8. Where appropriate, programmes should be established for the surveillance and maintenance of core components during service. Checks should be made for physical changes such as bowing, swelling, corrosion, wear and creep. These programmes should include examination of unloaded components, including components to be returned to the core for further service, in order to detect significant degradation during service. Maintenance programmes should include procedures to prevent the introduction of foreign materials into the reactor (see paras 4.25–4.27). Further recommendations on the surveillance and maintenance of items important to safety are provided in SSG-74 [6].

6.9. Testing and inspection of control rods and control rod drive mechanisms should be performed to ensure reliable control rod operation. The tests and inspections should be performed frequently enough to be able to discover at least the following anomalies in a timely manner:

(a) The immobility of (single or multiple) control rods due to the sticking of metal contacts;
(b) A significant increase in control rod travel time during a scram event;
(c) Ageing degradations (e.g. cracks due to embrittlement);
(d) Mechanical damage;
(e) Presence of material depositions and/or foreign materials.

7. PREPARATION OF FUEL FOR DISPATCH

7.1. Fuel should be removed from the storage facility only when duly authorized. This authorization should specify the fuel type, its position in the facility, its destination and the procedures to be applied during handling.

7.2. The fuel for loading into a transport package approved for use for such fuel (particularly in terms of criticality assessment) should be selected on the basis of its burnup, irradiation history and cooling time so that the radiation levels and decay heat levels remain within the specified limits for the package. If special removable neutron absorber curtains or similar devices are necessary, procedures should be established to ensure that these are in place before fuel is placed in the package. The package is required to be labelled in accordance with the applicable transport regulations (see para. 7.27 of SSR-2/2 (Rev. 1) [1]) and should be clearly marked with any other necessary means of identification.

7.3. Procedures should be established and implemented for the preparation of the transport package for transport off the site. These procedures should be followed to ensure, in particular, that the transport package is leaktight and has adequate cooling capability, and that the radiation levels and contamination levels comply with the applicable transport regulations. In addition, procedures should be followed to ensure that the equipment necessary for handling the transport package is available and has been functionally tested. The procedures should include measures such as the use of checklists with approvals and countersignatures for important hold points, to ensure that the contents of the transport package have been correctly loaded.

7.4. Vehicles used for the transport of fuel should be checked for contamination and radiation levels to ensure compliance with the applicable transport regulations before dispatch from the site.

7.5. Any package that has previously been used should initially be assumed to contain radioactive substances; the external contamination levels and radiation levels should be checked upon arrival at the site. If the levels of contamination and radiation exceed specified values, an investigation should be conducted to discover the cause and to determine the corrective actions to be taken.

7.6. Before a previously used (and supposedly empty) package is opened, it should be ensured that radiation monitors with alarms are in operation, and suitable measures should be taken (such as opening the packages under water) to prevent accidental exposure of personnel if significant quantities of radioactive material have remained in the package.

7.7. Requirements for the transport of radioactive material are established in SSR-6 (Rev. 1) [21], and associated recommendations are provided in IAEA Safety Standards Series No. SSG-26 (Rev. 1), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition) [24].

8. ADMINISTRATIVE AND ORGANIZATIONAL ASPECTS OF CORE MANAGEMENT AND FUEL HANDLING

8.1. The operating organization is responsible for all aspects of on-site fuel management. The specific organizational arrangements for core management might differ significantly from one another, depending on the practices and policies of the operating organization. Adequate design support should be provided to the operating personnel involved in core management. The operating organization should ensure that the plant management has been given the necessary authority and that responsibilities are clearly defined.

8.2. The responsibilities of the operating organization in respect of core and fuel management[11] should include the following:

(a) Establishing and maintaining a comprehensive core management programme (see para. 2.3) to ensure that the necessary assistance will be provided to the plant management to perform the core management and fuel handling tasks described in this Safety Guide;
(b) Ensuring that from the design stage onwards the plant management will be provided with the necessary data, design reports and documents relating to manufacturing, construction, commissioning and quality management to permit safe plant operation in accordance with the design specifications;
(c) Performing periodic surveillance of the fabrication of fuel and core components to ensure that they comply with specifications and meet the applicable requirements of the management system of the operating organization (see Requirement 11 of IAEA Safety Standards Series

[11] Liaison with other organizations might also be necessary.

No. GSR Part 2, Leadership and Management for Safety [25], and appendix III to GS-G-3.1 [12]);
(d) Ensuring that no modifications to fuel assemblies, core components, handling equipment or procedures are carried out without proper consideration and formal approval, as necessary (see also SSG-71 [4]);
(e) Ensuring that calculational methods are established and kept up to date in order to define fuel cycles and loading patterns for fuel and absorbers, to maintain compliance with operational limits and conditions, to verify operating procedures and establish associated surveillance arrangements, and to achieve the optimum utilization of fuel;
(f) Making arrangements for the examination of irradiated fuel to evaluate its performance;
(g) Making arrangements for the movement of fresh fuel, irradiated fuel and core components;
(h) Making arrangements for on-site storage and handling of fresh fuel, irradiated fuel and core components;
(i) Making arrangements for inspection and periodic maintenance of fuel handling equipment, in accordance with Requirement 31 of SSR-2/2 (Rev. 1) [1];
(j) Making arrangements for ageing management, in accordance with Requirement 14 of SSR-2/2 (Rev. 1) [1];
(k) Arrangements for the exclusion of foreign materials (see paras 4.25–4.27);
(l) Making arrangements to ensure that operating personnel are properly qualified and trained, in accordance with Requirement 7 of SSR-2/2 (Rev. 1) [1];
(m) Clearly defining responsibilities for all tasks and assigning them to appropriate personnel, in accordance with Requirement 3 of SSR-2/2 (Rev. 1) [1].

8.3. In addition, the operating organization should ensure that procedures are in place to control the various safety related aspects of core management and fuel handling, including the following:

(a) Receipt, storage, handling, inspection and positioning of fuel and core components;
(b) Recording of the location, exposure, physical condition and positioning of fuel and core components;
(c) Surveillance of the core;
(d) Tests to obtain values for core parameters, such as those listed in para. 2.34, as appropriate;

(e) Actions to be taken by operating personnel whenever core parameters are outside the limits and conditions for normal operation, and corrective actions to be taken to prevent safety limits from being exceeded (see SSG-70 [3]);
(f) Independent review of the performance of the core and of proposals for significant modifications to plant items and procedures (see SSG-71 [4]);
(g) Reporting and investigation of abnormal occurrences, including root cause analysis.

8.4. A safety policy is required to be established (see para. 4.2 of GSR Part 2 [25]) and this should meet the objectives of the fuel management programme (see Requirement 4 of GSR Part 2 [25]). The senior management should achieve these objectives by ensuring the communication of their expectations to staff, by providing sufficient resources (see para. 2.2(e) of GSR Part 2 [25]) and by monitoring the performance of personnel. The safety policy should specify the safety objectives and the technical and economic objectives, should establish expected safety performance levels and should clearly define the responsibilities for achieving these levels. The goals and objectives of activities relating to fuel management should be made achievable by means of appropriate procedures.

8.5. The safety policy should be based on maintaining the independence and adequate reliability of each level of defence in depth. The influence of human and organizational factors on one or more levels of defence in depth should be taken into account and addressed in all operational activities. A defence in depth approach should be generally applied to safety related activities in core management and fuel handling. These activities should be carefully planned, appropriately authorized by the plant management and carried out in accordance with approved procedures implemented by competent staff.

8.6. Adequate safety assessments and independent verifications should be carried out for different core management and fuel handling activities to ensure that such activities can be completed without affecting the safety of the plant.

8.7. Internal interfaces and interfaces with external organizations should be specified and documented by the operating organization (see section 4 of SSG-72 [5]). The documentation should specify what information needs to be exchanged between organizations and by whom, and the reviews and approvals that are necessary. When the operating organization arranges to obtain core management services (from other groups within the operating organization or from other organizations), these services should be readily accessible.

8.8. The operating organization is required to ensure there are sufficient qualified personnel for the safe operation of the plant (see Requirement 4 of SSR-2/2 (Rev. 1) [1]). The number of personnel needed for core management and fuel handling will depend on the tasks to be performed and on the following:

(a) The extent to which core management services, core related calculations, evaluations of reload safety and transient analyses are to be provided by contractors;
(b) The strategies relating to optimization of the core (such as company policies with respect to new fuel designs or new suppliers, increasing the burnup, developing low leakage cores and utilizing thermal performance margins).

8.9. The operating organization should identify the key competences necessary (e.g. in performing criticality assessment and transient analysis, in using the relevant tools) for carrying out core calculations. It should consider whether these competences should be provided from within the operating organization (either by on-site personnel or from elsewhere within the organization) or by external contractors. Whichever option is chosen, the operating organization should ensure that the necessary level of competence is established and maintained. If tasks are to be undertaken by external contractors, the operating organization is required to have sufficient knowledge of the work done on its behalf to judge its technical validity (see Requirement 11 of GSR Part 2 [25]).

8.10. Quality management for the fuel management programme should be extended to include the supply chain. The operating organization should ensure that the manufacturers and designers have acceptable quality management programmes. The operating organization should also ensure that the manufacturers and designers comply with the management programmes, for example by performing periodic audits.

8.11. Lessons from experience gained from events at the plant and outside the plant are required to be applied to enhance safe operation (see Requirement 24 of SSR-2/2 (Rev. 1) [1] and para. 6.7 of GSR Part 2 [25]). Safety relevant information obtained from operating experience relating to fuel should be recorded and should be exchanged with the supplier, with other plants of the same operating organization, with the regulatory body (if applicable) and with other operating organizations, particularly those that operate similar reactors.

9. DOCUMENTATION FOR CORE MANAGEMENT AND FUEL HANDLING ACTIVITIES

9.1. Requirement 15 of SSR-2/2 (Rev. 1) [1] states that “**The operating organization shall establish and maintain a system for the control of records and reports.**” For the safe operation of a nuclear power plant, the operating organization should have adequate information on the fuel, core parameters and core components, and on the handling equipment for the fuel and for core components. This information should include details of the design and installation and the results of safety analyses.

9.2. The information obtained during commissioning and subsequent operation should be evaluated and retained as it becomes available. This information should be kept in a comprehensive record keeping system covering core management and handling activities for fuel and core components. This system should be designed to provide sufficient information for the correct handling of fuel and core components on the site, and for detailed analysis of the performance of the fuel and of activities relating to core safety throughout the operating life of the plant. Further recommendations on record keeping are provided in GS-G-3.1 [12].

9.3. Records important to core management and the handling of fuel and core components should typically include the following, as appropriate:

(a) The design basis, material properties and dimensions of the core;
(b) Plant operational records;
(c) Data relating to installation tests and commissioning tests and records of special operating tests;
(d) Core operating history (e.g. hourly logs of parameters such as temperature and flow rate from the plant computer);
(e) Power, energy and heat balance;
(f) Reactivity balance and critical configuration during startup;
(g) In-core flux measurements;
(h) Refuelling programmes and supporting information;
(i) Refuelling patterns and schedules;
(j) Location of each fuel assembly throughout its time on the site;
(k) History of burnup for each individual fuel assembly;
(l) Data on fuel failures;
(m) Results of examinations of fuel and components;
(n) Status, repair history, modifications and test results for handling equipment for fuel and for core components;

(o) Coolant and moderator inventories, chemical quality and impurities;
(p) Records relating to core management (e.g. calculational notebooks, computer code descriptions);
(q) Computer calculations of core parameters, power and neutron flux distributions, isotopic changes and additional data considered important to fuel performance;
(r) Operational data to validate methods, to provide input for the refuelling plan and to form the basis for the evaluation of operational safety;
(s) Comparisons of test results and validation of computational methods.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), IAEA, Vienna (2016).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), IAEA, Vienna (2016).
[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-70, IAEA, Vienna (in press).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Modifications to Nuclear Power Plants, IAEA Safety Standards Series No. SSG-71, IAEA, Vienna (in press).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, The Operating Organization for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-72, IAEA, Vienna (in press).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Testing, Surveillance and Inspection in Nuclear Power Plants, IAEA Safety Standards Series No. SSG-74, IAEA, Vienna (in press).
[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-75, IAEA, Vienna (in press).
[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Conduct of Operations at Nuclear Power Plants, IAEA Safety Standards Series No. SSG-76, IAEA, Vienna (in press).
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, IAEA, Vienna (2019).
[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of the Reactor Core for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-52, IAEA, Vienna (2019).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Deterministic Safety Analysis for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-2 (Rev. 1), IAEA, Vienna (2019).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Equipment Qualification for Nuclear Installations, IAEA Safety Standards Series No. SSG-69, IAEA, Vienna (2021).

[14] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Fuel Handling and Storage Systems for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-63, IAEA, Vienna (2020).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7, IAEA, Vienna (2018).

[17] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, WORLD METEOROLOGICAL ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7, IAEA, Vienna (2015).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/ Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection Against Internal and External Hazards in the Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-77, IAEA, Vienna (2022).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-28, IAEA, Vienna (2014).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2018 Edition, IAEA Safety Standards Series No. SSR-6 (Rev. 1), IAEA, Vienna (2018).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Spent Nuclear Fuel, IAEA Safety Standards Series No. SSG-15 (Rev. 1), IAEA, Vienna (2020).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Accident Management Programmes for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-54, IAEA, Vienna (2019).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition), IAEA Safety Standards Series No. SSG-26 (Rev. 1), IAEA, Vienna (2022).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016).

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