IAEA Safety Standards

for protecting people and the environment

Core Management and Fuel Handling for Research Reactors

Specific Safety Guide

No. SSG-82

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

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

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

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 RESEARCH REACTORS

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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-82

CORE MANAGEMENT AND FUEL HANDLING FOR RESEARCH REACTORS

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
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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.

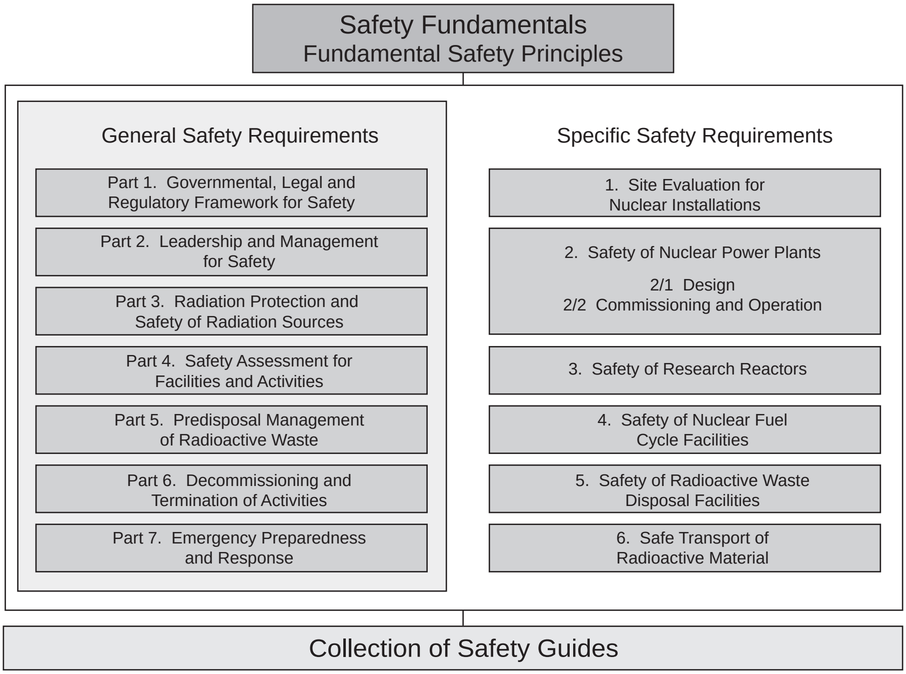

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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.

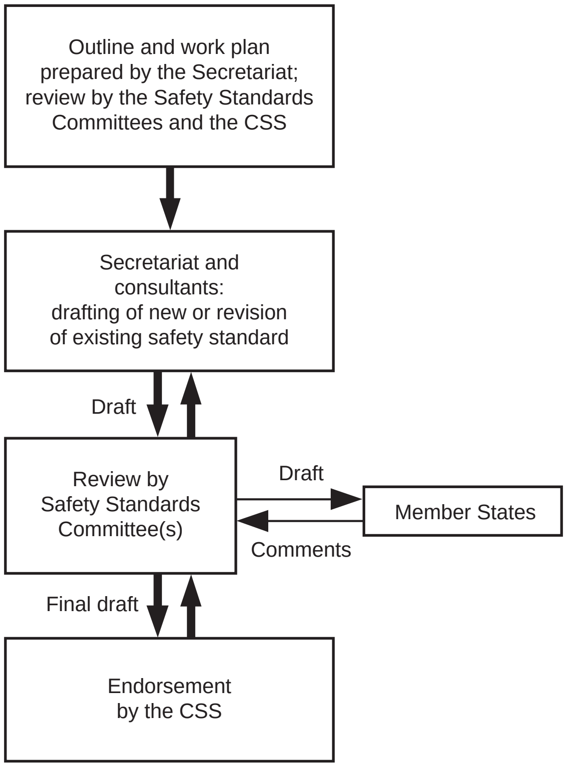

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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

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

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

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

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Requirements for the safety of research reactors, with particular emphasis on their design and operation, are established in IAEA Safety Standards Series No. SSR-3, Safety of Research Reactors [1].

1.2. This Safety Guide provides recommendations on core management and fuel handling for research reactors.

1.3. This Safety Guide was developed in parallel with seven other Safety Guides on the safety of research reactors, as follows:

- — IAEA Safety Standards Series No. SSG-80, Commissioning of Research Reactors [2];
- — IAEA Safety Standards Series No. SSG-81, Maintenance, Periodic Testing and Inspection of Research Reactors [3];
- — IAEA Safety Standards Series No. SSG-83, Operational Limits and Conditions and Operating Procedures for Research Reactors [4];
- — IAEA Safety Standards Series No. SSG-84, The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors [5];
- — IAEA Safety Standards Series No. SSG-85, Radiation Protection and Radioactive Waste Management in the Design and Operation of Research Reactors [6];
- — IAEA Safety Standards Series No. SSG-10 (Rev. 1), Ageing Management for Research Reactors [7];
- — IAEA Safety Standards Series No. SSG-37 (Rev. 1), Instrumentation and Control Systems and Software Important to Safety for Research Reactors [8].

1.4. Additional recommendations on the safety of research reactors are provided in IAEA Safety Standards Series Nos SSG-20 (Rev. 1), Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report [9], and SSG-24 (Rev. 1), Safety in the Utilization and Modification of Research Reactors [10].

1.5. The terms used in this Safety Guide are to be understood as defined and explained in the IAEA Nuclear Safety and Security Glossary [11].

1.6. This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-4.3, Core Management and Fuel Handling for Research Reactors[1].

OBJECTIVE

1.7. The objective of this Safety Guide is to provide recommendations on core management and fuel handling for research reactors to meet the relevant requirements established in SSR-3 [1], in particular Requirements 58 and 78.

1.8. The recommendations provided in this Safety Guide are aimed at operating organizations of research reactors, regulatory bodies and other organizations involved in a research reactor project.

SCOPE

1.9. This Safety Guide is primarily intended for use for heterogeneous, thermal spectrum research reactors that have a power rating of up to several tens of megawatts. For research reactors of higher power, specialized reactors (e.g. fast spectrum reactors) and reactors that have specialized facilities (e.g. hot or cold neutron sources, high pressure and high temperature loops), additional guidance may be needed. For such research reactors, the recommendations provided in IAEA Safety Standards Series No. SSG-73, Core Management and Fuel Handling for Nuclear Power Plants [12], might be more suitable. Homogeneous reactors and accelerator driven systems are outside the scope of this publication.

1.10. Some research reactors, critical assemblies and subcritical assemblies with a low hazard potential might need a less comprehensive core management and fuel handling programme. While all recommendations in this Safety Guide are to be considered, some might not be applicable to such research reactors, critical assemblies and subcritical assemblies (see Requirement 12 and paras 2.15–2.17 of SSR-3 [1], as well as IAEA Safety Standards Series No. SSG-22 (Rev. 1), Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors [13]).

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Core Management and Fuel Handling for Research Reactors, IAEA Safety Standards Series No. NS-G-4.3, IAEA, Vienna (2008).

1.11. In this Safety Guide, subcritical assemblies will be mentioned separately only if a specific recommendation is not relevant for, or is applicable only to, subcritical assemblies.

1.12. The recommendations for core management in this Safety Guide include the management of in-core and out-of-core experimental devices. The incorporation of newly designed fuel assemblies into an existing core is also considered, and the recommendations can be applied to the conversion of research reactors to use low enriched uranium instead of high enriched uranium.

1.13. In this publication, ‘core management’ refers to activities associated with fuel assemblies, management of core components, and reactivity control. The recommendations on core management cover core calculations, experimental verifications, movements and change in fuel elements, and movements and change in other core components.

1.14. In this publication, ‘fuel handling’ refers to the movement, storage and control of fresh fuel and irradiated fuel, whether manually or by means of automated systems. The recommendations on fuel handling cover the following:

(a) Receipt of fresh fuel assemblies;
(b) Storage and handling of fuel assemblies and other core components;
(c) Inspection of fuel assemblies;
(d) Loading and unloading of fuel assemblies and core components;
(e) Inspection of irradiated fuel;
(f) Insertion and removal of other reactor materials, either manually or by means of automated systems;
(g) Preparation of fuel assemblies for transport;
(h) Loading of a transport cask or package with irradiated fuel assemblies.

1.15. This Safety Guide does not include recommendations on safety precautions for transport beyond the site or for the off-site storage and ultimate disposal of irradiated fuel assemblies and core components. This Safety Guide does not cover the handling of medical and industrial radioisotopes produced in the research reactor. Nuclear security and emergency preparedness and response are also outside the scope of this Safety Guide.

1.16. Aspects of fuel accounting not directly related to safety are not considered in this Safety Guide; thus, safeguards aspects are not considered.

1.17. Core management involving the total redesign of the reactor core (e.g. conversion of a conventional core with many fuel assemblies to a compact core with few assemblies) is beyond the scope of this Safety Guide; instead, the requirements for the design of research reactors established in SSR-3 [1] should be followed. Similarly, the design and installation of a new experimental device that has major safety significance or the potential to give rise to off-site radiological consequences is outside the scope of this Safety Guide.

STRUCTURE

1.18. This Safety Guide consists of nine sections and one annex. Sections 2 and 3 provide recommendations on the management system for a research reactor as it relates to core management and fuel handling, and on the core management programme, respectively. Section 4 provides recommendations on best practices relating to the main aspects of the handling and storage of fresh fuel. Section 5 provides recommendations on refuelling activities. Section 6 provides recommendations on aspects of the handling, storage and inspection of irradiated fuel. Section 7 provides recommendations on the handling and storage of core components, in particular those that have been irradiated. Section 8 provides recommendations on the preparatory arrangements for the dispatch of fuel assemblies from the site. Section 9 provides recommendations on general aspects of documentation for core management and fuel handling. The Annex briefly presents the reasons to undertake core management at research reactors.

2. APPLICATION OF THE MANAGEMENT SYSTEM TO CORE MANAGEMENT AND FUEL HANDLING AT A RESEARCH REACTOR

2.1. A management system that integrates safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements for the research reactor project is required to be developed (see Requirement 4 of SSR-3 [1]). The documentation of the management system should describe the system that controls the development and implementation of all activities at the research reactor, including core management and fuel handling. Approval of the management system (or parts thereof) by the regulatory body may be required (see para. 4.12 of SSR-3 [1]).

2.2. In accordance with paras 4.13–4.20 of SSR-3 [1], the management system is required to cover four functional categories, as follows:

(a) Management responsibility: includes providing the means and management support needed to achieve the organization's objectives (see paras 2.7–2.9 of this Safety Guide);
(b) Resource management: includes the measures needed to ensure that resources essential to the implementation of strategy and the achievement of the organization's objectives are identified and made available (see paras 2.10–2.15 of this Safety Guide);
(c) Process implementation: includes those actions and tasks needed to achieve the goals of the organization (see paras 2.16–2.20 of this Safety Guide);
(d) Measurement, assessment and improvement of the management system: includes activities conducted to evaluate the effectiveness of management processes and work performance (see paras 2.21–2.24 of this Safety Guide).

General requirements for the management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [14]. Specific recommendations are provided in IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [15].

2.3. As part of the management system, the arrangements for core management and fuel handling should be established early in the research reactor project. These arrangements should apply to all items and processes important to safety and should include the means of establishing controls over core management and fuel handling activities. This should provide confidence that these activities are performed in accordance with established codes, standards, specifications, procedures and administrative controls, as required by para. 4.16 of SSR-3 [1]. The roles and responsibilities of personnel involved in core management and fuel handling should be defined in the management system.

2.4. In establishing the management system, a graded approach in accordance with the relative importance to safety of each item or process (e.g. core configuration, critical experiments) is required to be used (see para. 4.7 of SSR-3 [1]).

2.5. The objective of the management system as applied to core management and fuel handling should be to ensure that the research reactor meets the following:

(a) Regulatory requirements;
(b) Design requirements and assumptions;
(c) The safety analysis report (see Requirement 1 of SSR-3 [1]);

(d) The operational limits and conditions (OLCs) for the research reactor (see Requirement 71 of SSR-3 [1]);
(e) Administrative requirements associated with the management of the research reactor.

2.6. The management system is required to support the development, implementation and enhancement of a strong safety culture (see paras 1.5(b) and 4.9 of GSR Part 2 [14]). This safety culture should be applied in all aspects of the programme for core management and fuel handling.

MANAGEMENT RESPONSIBILITY FOR CORE MANAGEMENT AND FUEL HANDLING AT A RESEARCH REACTOR

2.7. The operating organization is responsible for the overall safety of the research reactor, and the reactor manager[2] has direct responsibility for its safe operation. In most research reactors, the reactor manager has direct responsibility for both core management and fuel handling. In some cases, an analysis group may perform certain aspects of core management (e.g. design, safety analysis, predictions of performance). In all cases, the operational aspects of core management and the fuel handling activities at the research reactor are the direct responsibility of the reactor manager. The reactor manager should participate in the core management and fuel handling activities by means of the following:

(a) Having frequent contact with core management and fuel handling personnel, including observation of work in progress;
(b) Establishing and implementing a set of safety performance indicators for core management and fuel handling;
(c) Participating in evaluations of the programme for core management and fuel handling;
(d) Providing feedback derived from core management and fuel handling performance indicators for use in the operation of the research reactor.

2.8. The operating organization is responsible for establishing clear lines of authority and communication among personnel involved in core management and fuel handling activities, for preparing and controlling implementation procedures,

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[2] The reactor manager is the member of the reactor management to whom direct responsibility and authority for the safe operation of the reactor are assigned by the operating organization and whose primary duties constitute the discharge of this responsibility.

for training and retraining personnel as necessary, and for developing and nurturing a strong culture for safety.

2.9. Records essential to the performance and verification of core management and fuel handling activities should be controlled using a system that includes their identification, approval, review, filing, retrieval and disposal.

RESOURCE MANAGEMENT FOR CORE MANAGEMENT AND FUEL HANDLING AT A RESEARCH REACTOR

2.10. Paragraph 4.15(c) of SSR-3 [1] states that "The management system shall ensure that: ...The equipment, tools, materials, hardware and software necessary to conduct the work in a safe manner are identified, provided, checked, verified and maintained." Consequently, equipment, tools, materials, hardware and software used for core management and fuel handling are required to be identified and controlled to ensure their proper use, and to be checked, verified and maintained. Equipment used for monitoring, data collection, and inspections and tests in relation to core management and fuel handling are required to be qualified for the operating environmental conditions and calibrated as necessary (see Requirements 29 and 31 of SSR-3 [1]).

2.11. In accordance with para. 7.28 of SSR-3 [1], the operating organization is required to identify the key competences necessary for core management and fuel handling activities, such as competence in criticality assessment and the analysis of transients, and expertise in techniques for performing core calculations. For low power research reactors, envelopes and margins established by the research reactor supplier in the initial safety analysis or design report may be sufficient for the lifetime of the research reactor, provided there is no significant change in the design and utilization of fuel assemblies and core components. For higher power research reactors, assigning an individual or group of experts to provide sufficient capability for analysis may be necessary. The operating organization is required to ensure that the necessary competences are maintained to ensure that personnel performing safety related functions are capable of safely performing their duties correctly to meet the required level of safety (see paras 7.28 and 7.29 of SSR-3 [1]).

2.12. If core management and fuel handling tasks are to be undertaken by contractors, the operating organization, including the reactor manager, is required to have sufficient knowledge of the work undertaken to judge its technical validity (see para. 4.34 of GSR Part 2 [14]) and should know where to seek advice and assistance if necessary.

2.13. Paragraph 4.15(b) of SSR-3 [1] states that “The management system shall ensure that: …External personnel (including suppliers and experimenters) are adequately trained and qualified and perform their activities under the same controls and to the same standards as the reactor personnel.”

2.14. External personnel should receive the same general training provided to operating personnel, as well as specific training in core management and fuel handling procedures and methods. Experienced and qualified personnel may be allowed to forgo such training by proving their proficiency. However, they should, in any case, be instructed on the work to be done at the research reactor, and they should be aware of the structure of the reactor core and of all possible scenarios during fuel handling procedures that can lead to undesired events or accidents. Research reactor supervisors should review the work of external personnel during preparation for the work and during testing and acceptance testing.

2.15. Paragraph 4.15(a) of SSR-3 [1] states that “The management system shall ensure that: …Suppliers, manufacturers and designers of structures, systems and components important to safety have an effective integrated management system in place, with audits to confirm its effectiveness.”

PROCESS IMPLEMENTATION FOR CORE MANAGEMENT AND FUEL HANDLING AT A RESEARCH REACTOR

2.16. The activities and the interfaces between different groups involved in core management and fuel handling should be planned, controlled and managed to ensure effective communication and the clear assignment of responsibility.

2.17. The management system should include provisions to ensure that inspection, testing, verification and validation activities are completed before the implementation or operational use of a new core design or experiment design or a new handling technique. Processes for monitoring and measurement should be established within the management system to provide evidence of compliance with design requirements and satisfactory completion of in-service inspections.

2.18. As part of the implementation of the management system, the operating organization should ensure that approved procedures are established to control the various safety related aspects of core management and fuel management, including the following:

(a) Procurement, receipt, inspection and storage of fresh fuel, handling, loading, utilization, unloading and storage of spent fuel, movement and testing of fuel assemblies and core components;
(b) Recording of the identity, locations, associated dose rates, physical condition and disposition of fuel assemblies and core components;
(c) Core surveillance;
(d) Appropriate tests to obtain values for core parameters, such as those described in para. 3.24;
(e) Actions to be taken by the reactor operator whenever core parameters are outside the OLCs for normal operation, and corrective actions to be taken to prevent OLCs from being exceeded;
(f) Independent review of the performance of the core and of proposals for significant modifications to components and procedures (see SSG-24 (Rev. 1) [10]);
(g) Reporting and investigation of unusual occurrences, including root cause analysis;
(h) Management of interfaces with nuclear security (see Requirement 90 of SSR-3 [1]).

2.19. In support of the processes established under the management system, documents such as the core management programme, procedures, specifications and drawings should be prepared, reviewed, updated, approved, issued, validated as necessary and archived. Procedures for core management and fuel handling should be developed in consultation with security specialists (including physical and computer security specialists) to ensure that the interfaces between safety and security are adequately considered.

2.20. The management system should include procurement activities for core management at the research reactor and should be extended to include the evaluation of suppliers in accordance with Requirement 11 of GSR Part 2 [14]. Suppliers should be evaluated and selected on the basis of specified criteria. The operating organization should ensure that the manufacturers and designers have acceptable management systems and should ensure through audits that they comply with the management system of the operating organization of the research reactor.

MEASUREMENT, ASSESSMENT AND IMPROVEMENT OF THE MANAGEMENT SYSTEM FOR A RESEARCH REACTOR

2.21. Paragraph 4.20 of SSR-3 [1] states:

> "The effectiveness of the management system shall be regularly measured and assessed through independent assessments and self-assessments. Weaknesses in processes shall be identified and corrected. The operating organization shall evaluate the results of such assessments and shall determine and take the necessary actions for continuous improvements."

2.22. Suitable methods should be applied for monitoring the effectiveness of the core management and fuel handling programme. To be effective, the programme should comply not only with the recommendations of this Safety Guide but also with the needs of the experimental programme.

2.23. An organizational unit should be established with responsibility for conducting independent assessments of the core management and fuel handling programme. This unit is usually the reactor safety committee, as described in paras 7.26 and 7.27 of SSR-3 [1].

2.24. The operating organization should evaluate the results of the independent assessments and should take necessary actions to implement recommendations and suggestions for improvement. Lessons identified from operating experience are required to be applied to enhance safe operation (see Requirement 88 of SSR-3 [1]). Safety related information on core management and fuel handling obtained from operating experience should be recorded and should be exchanged with the supplier, with other research reactor operating organizations and with the regulatory body.

3. CORE MANAGEMENT FOR A RESEARCH REACTOR

3.1. Requirement 78 of SSR-3 [1] states that "**Core management and fuel handling procedures for a research reactor facility shall be established to ensure compliance with operational limits and conditions and consistency with the utilization programme**." The primary objective of core management is to ensure the safe, reliable and optimum use of the nuclear fuel in the research reactor, while remaining within the limits imposed by the design of the fuel assembly and the design of the research reactor, on the basis of the safety analysis contained in the safety analysis report and the OLCs derived from the safety analysis. The secondary objective is to meet the needs of the utilization programme (e.g. the need for neutron flux for experiments) while keeping within the OLCs.

3.2. The core arrangements and core components, including experimental devices, should be determined during the design stage of the research reactor. However, it may become necessary to change the reactor core and core components during the operational lifetime of the research reactor for a variety of reasons, such as the need to change fuel assemblies or support different utilization activities (see the Annex). This may lead to a corresponding change in the arrangements for handling of fuel assemblies and core components. In such cases, pertinent information from designers, manufacturers and other operating organizations should be used.

3.3. Successful implementation of the core management programme involves the following:

(a) Planning and prioritization of work;
(b) Availability of qualified personnel with suitable skills;
(c) Availability of appropriate computational methods and tools;
(d) Availability of approved procedures;
(e) Addressing of all applicable regulatory requirements;
(f) Compliance with OLCs;
(g) Availability and operability of special tools and equipment;
(h) A satisfactory working environment;
(i) Implementation and execution of the necessary inspections and tests.

3.4. While the details of core management will depend on the type of research reactor and the organization of the facility, 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 fuel cycle so as to ensure that core parameters remain within the OLCs. Core management functions include core design (specification of fuel assembly loading and shuffle patterns to provide optimum fuel burnup and desired neutron fluxes), experiment design and installation, fuel assembly procurement, reactivity determinations, and core performance monitoring.

(b) To determine core operating strategies that permit maximum operating flexibility for research reactor utilization and optimum nuclear fuel utilization while remaining within the OLCs.
(c) To ensure that only fuel assemblies and experimental devices of approved design are used.

3.5. The following need to be ensured with regard to core management at a research reactor:

(a) Validated methods and codes are required to be used (see para. 7.79(a) of SSR-3 [1]) to determine appropriate positions in the core for locating the nuclear fuel, reflector, safety devices (control rods[3], valves for dumping the moderator and/or reflector, burnable neutron absorbers), experimental devices, irradiation devices and moderators.
(b) The integrity of the fuel assembly is required to be ensured at all times during the utilization of the reactor by maintaining relevant core configuration parameters in accordance with the design intent and assumptions, as specified in the OLCs for the research reactor (see para. 7.79(e) of SSR-3 [1]).
(c) The reactor core should be monitored to ensure that reactor operation is conducted at all times in accordance with the design intent and assumptions, as specified in the OLCs for the research reactor. The effects and safety implications of the irradiation of core material, core components, experimental devices and irradiation facilities are required to be assessed (see para. 7.79(b) of SSR-3 [1]).
(d) The integrity of the fuel cladding is required to be continuously monitored (not necessarily monitored 'on-line' in the research reactor but commonly monitored indirectly by monitoring the fission product activity in the primary coolant and off-gas systems) (see para. 7.82 of SSR-3 [1]). In the event of detection of fuel failure, an investigation is required to be initiated to identify the failed fuel assembly and to unload it from the core if necessary[4] (see para. 7.79(e) of SSR-3 [1]).
(e) Fuel procurement is required to be performed on the basis of specifications in accordance with the design intent and the OLCs (see paras 4.19 and 7.7 of SSR-3 [1]).

[3] Some research reactors have other forms of reactivity control devices (e.g. plates). In this Safety Guide, the term 'control rod' is generally used for all forms of devices for research reactor reactivity control.

[4] For research reactors with a closed primary circuit, it may be possible to continue operation of the reactor, depending on the activity limit of the primary circuit as specified in the OLCs.

(f) Approved procedures are required to be followed for loading and unloading fuel assemblies and other core components (see para. 7.79(d) and (f) of SSR-3 [1]).
(g) Baseline information on all the parameters relating to the nuclear fuel and core configuration is required to be maintained and updated (see para. 7.79(c) of SSR-3 [1]).

3.6. The defence in depth concept should be applied to safety related activities in research reactor operations, including core management and fuel handling. These activities should be carefully planned, appropriately authorized by the reactor management and performed in accordance with approved procedures implemented by competent personnel. Adequate safety assessments and independent verifications should be performed for different core management and fuel handling activities to ensure that such activities can be completed without affecting the safety of the research reactor.

CORE CALCULATIONS FOR A RESEARCH REACTOR

Analyses of core conditions and characteristics

3.7. A comprehensive safety analysis of the research reactor, including core design analysis, is required to be performed and documented in the safety analysis report (see Requirements 1 and 41 of SSR-3 [1]; see also SSG-20 (Rev. 1) [9]). The OLCs are required to be developed on the basis of this analysis (see para. 7.33 of SSR-3 [1]). Provided that the reactor operations do not lead to core conditions that differ from those considered in the safety analysis, a detailed reanalysis should not be necessary. However, if there are (a) any changes in core configuration, (b) differences in the types of fuel assembly in use, (c) differences between fuel assemblies because of the burnup history, (d) other core components present or (e) any other conditions that deviate from those considered in the current safety analysis, a more comprehensive analysis is required to be performed (see para. 7.99(a) of SSR-3 [1]). The analysis should be performed before restart of operations and should take into consideration the changes and new conditions to ensure that the research reactor continues to be operated within the OLCs with adequate margin.

3.8. Appropriate methods and techniques should be used to predict reactor behaviour during operation. Computational models, numerical methods and nuclear data used to predict this behaviour should be verified, validated and approved. Uncertainties in calculations and measurements should be taken into account.

3.9. To verify compliance with the OLCs, the following core parameters should be considered and analysed, to the extent necessary, for both steady state and transient conditions:

(a) Variations in reactivity with fuel burnup, and actions needed to maintain core reactivity (e.g. changes in control rod positions, the addition of fuel assemblies, changes in core reflection);
(b) Location and reactivity worth of control rods for all core configurations, burnups and xenon concentrations, including verification that the shutdown margin is in accordance with the OLCs;
(c) Location and reactivity worth of in-core and out-of-core experimental devices and materials being irradiated;
(d) Local and global reactivity coefficients of temperature (for fuel, moderator and coolant), power, pressure and void over the normal operating range, for anticipated operational occurrences and transient conditions;
(e) Neutron flux and power distribution in the core components and the nuclear fuel, and the effect of control rod movement on those parameters;
(f) Fuel and moderator temperatures, coolant flow rates, pressure drop and temperature, and density and thermal margins of the coolant;
(g) Fuel burnup level in each fuel assembly;
(h) Shadow effects of control rods and core experiments on neutron flux detectors.

3.10. Due consideration should be given to the effect on the performance of the research reactor of experimental devices and irradiation devices, in or adjacent to the core, that were not considered in the original design. A safety analysis should be performed to evaluate the effect on the research reactor of a failure in these devices. The effects of changes in the reactor on the experiment or the irradiation programme should also be considered. Recommendations on safety analysis for experimental devices are provided in SSG-24 (Rev. 1) [10].

3.11. Core reactivity changes and the associated effects during reactor operation due to the buildup of fission products, fuel burnup and refuelling, and the resulting control rod movements should be predicted and compared with measured parameters. This should be done to confirm that there is sufficient reactivity control at all times to ensure that the research reactor can be shut down safely and that it would remain shut down following all normal operational processes, anticipated operational occurrences and design basis accidents.

3.12. Because of their safety significance during reactor operation, the following items should be analysed, as appropriate:

(a) The variation in reactivity worth of control rods due to irradiation effects;
(b) The effects of irradiation and the shadow effects of control rods and experimental devices on neutron flux detectors and, in particular, the resulting variation in their sensitivity;
(c) The adequacy of the strength of the neutron source and of the sensitivity and locations of neutron detectors for startup, especially following a long shutdown (the irradiated fuel and photoneutrons might not constitute a source of sufficient strength).

3.13. If there are significant discrepancies (i.e. greater than the variation that can be attributed to uncertainties in the calculations and the measurements) between the predictions made on the basis of reactor core calculations and the measurements of core characteristics, the research reactor should be placed in a safe condition (by shutting it down if necessary). The calculations and the measurements should be reviewed to determine the cause of the discrepancies. A conservative approach involving measurements of key core parameters (e.g. core effective multiplication factor (k_{eff}), core critical mass, control rod worth, excess reactivity, shutdown margin) should be adopted for making decisions on further operation. Necessary corrective actions should be taken after the causes of the problem have been identified.

Computational methods for core calculations

3.14. The operating organization should ensure that the management system (see Section 2) covers the use of computational methods and tools for core management.

3.15. The management system should specify that the input values and computational tools and methods used for in-core fuel management and experiment management are validated, benchmarked, amended and kept up to date, as necessary. Independent verification of the computational results (ideally by separate analysts using diverse tools and methods) should be mandatory for significant core management calculations. Special emphasis should be placed on the validation of methods used to deal with issues such as extended burnup, new materials, design modifications, new experimental devices and power increases.

3.16. All modifications to the software and databases used for core calculations should be reviewed and evaluated for their ability to predict core performance accurately. They should be independently verified and functionally tested (e.g. by comparing predicted code results with benchmark models) in accordance with standard methods and procedures for the maintenance of software, which could include approval by the reactor safety committee, regulatory body or other competent body before implementation. Physical and/or administrative controls should be established to ensure the integrity and reliability of the associated computer programs and databases.

3.17. The operating organization should ensure that personnel performing core calculations are qualified and properly trained in accordance with Requirement 70 of SSR-3 [1].

CORE OPERATION AT A RESEARCH REACTOR

3.18. To ensure the safe operation of the reactor core, a detailed programme for its operation and experimental utilization should be established in advance of core operation. Optimization of the research reactor utilization programme and nuclear fuel utilization, and flexibility in core operation and reactor utilization, should not compromise safety. The core operation programme should include the following procedures and engineering practices:

(a) Ensuring that all pre-startup procedures have been performed, that functional tests have been completed and that all the necessary documents and procedures have been updated prior to the startup of the research reactor;
(b) Ensuring that core parameters conform with the design intent and assumptions, as specified in the OLCs, by performing relevant measurements of criticality and shutdown margin, low power physics tests, core physics measurements (including the reactivity effects of experimental devices), and power ascension tests during the initial research reactor startup and, as appropriate, during subsequent startups;
(c) Establishing and implementing surveillance programmes for all in-core fuel assemblies and for the functions of experiment management and reactivity management.

3.19. To ensure the safe operation of the core, the following properties and conditions should be taken into account, as appropriate:

(a) The conformance of fresh fuel to design specifications;
(b) The fuel loading pattern;
(c) The reactivity shutdown margin;

(d) The maximum allowed excess of reactivity;
(e) The rates of addition and removal of reactivity;
(f) The coefficients of reactivity and reactivity worth of experimental devices and the materials being irradiated;
(g) The conformance of control rod characteristics, including speed of insertion and withdrawal, with design specifications;
(h) The characteristics of the control systems and protection systems;
(i) The neutron flux and power distribution, including perturbations by experiments and by materials being irradiated;
(j) Heat transfer, coolant flow and thermal margins in nuclear fuel and in experiments;
(k) Heat dissipation from the core in all operational states and under accident conditions;
(l) Coolant chemistry, moderator chemistry and moderator condition;
(m) Ageing effects resulting from irradiation, thermal stresses, corrosion and fission density limitations;
(n) The fission product activity in the primary coolant and off-gas system;
(o) Reactivity, chemical and physical effects of failures in experimental devices.

3.20. Operating procedures for research reactor startup, power operation, shutdown and refuelling should include precautions, in accordance with OLCs, that are necessary for maintaining the safe operation of the core. The operating procedures should cover the following, as appropriate:

(a) Identification of the instruments as well as the calibration and assessment methods to be used by operating personnel, so that relevant reactor parameters can be monitored within ranges consistent with the design intent and the safety analysis, as reflected in the OLCs;
(b) Pre-startup checks, including the fuel assembly loading pattern and the condition of experimental devices;
(c) Safety system settings to avoid damage to the nuclear fuel or the core, with account taken of changes in core conditions due to fuel burnup, xenon concentration or refuelling;
(d) Operating history of each fuel assembly, especially before refuelling;
(e) Parameters to be recorded for comparison with predicted core conditions;
(f) Limits for chemical parameters of the primary coolant and the moderator;
(g) Limits on primary coolant flow, primary coolant pressure difference across the core, rate of power ascension, fission and power densities, and neutron flux tilts;
(h) Actions to be taken when the limits are reached or exceeded;
(i) Actions to be taken in the event of control rod malfunction;

(j) Criteria for determining the failure of fuel assemblies and experimental devices and the actions to be taken upon detection of failures.

CORE MONITORING AT A RESEARCH REACTOR

3.21. A core monitoring programme should be established to ensure that core parameters (and trends in these parameters) are monitored and evaluated for the following purposes:

(a) To determine that the core parameters are acceptable and that the actual core performance is consistent with core design requirements and in compliance with the OLCs;
(b) To ensure that values of key operating parameters are recorded and retained in a logical and consistent manner;
(c) To detect abnormal core behaviour.

3.22. The core monitoring programme may involve parameters that are directly measurable, as well as values of non-measurable parameters derived from measurable parameters. When experimental or irradiation devices are located in or adjacent to the core, the status of these devices, the impact on core parameters and the need for additional measurements to characterize the appropriate combinations of conditions should be considered in the monitoring programme. Key core parameters should be continuously monitored in the control room, with more detailed measurements taken at a suitable frequency during reactor operation, to ensure that the core parameters remain within the OLCs and that any corrective actions can be taken when necessary.

3.23. Core conditions should be monitored and compared with predictions to determine whether the conditions conform with the design intent and assumptions, as specified in the OLCs (see SSG-83 [4]). If the core conditions do not conform, appropriate action should be taken to maintain the research reactor in a safe condition. If the predicted conditions cannot be met, corrective actions should be taken in accordance with the limiting conditions for safe operation.

3.24. The results of core monitoring and testing should also be used for review and updating of the refuelling programme and for optimization of core performance. Parameters to be monitored (either continuously or at appropriate intervals), and for which trends should be identified and evaluated, include the following, as appropriate:

(a) Operability, positions and patterns of control rods (or other reactivity control devices) and zonal neutron absorbers.
(b) Reactivity as a function of control rod position or moderator level.
(c) Scram time following a reactor trip (e.g. moderator and reflector dump time, absorber insertion time).
(d) Primary coolant availability (e.g. reactor water level).
(e) Pressure, flow and temperature rise of the coolant and the coolant inlet and outlet temperatures in the primary and secondary circuits, as applicable.
(f) Moderator temperature and mass flow.
(g) Fuel and core component temperatures, as applicable.
(h) Derived values for the following:
    (i) Thermal power output from the core;
    (ii) Temperatures of fuel and core components (where not measured);
    (iii) Local neutron flux peaking factors (power peaking factors);
    (iv) Heat generation in the moderator and core components;
    (v) Margins to thermal limits.
(i) Activity values including fission product activity in the primary coolant and the off-gas system.
(j) Physical and chemical parameters of the moderator and primary coolant, such as pH, conductivity, and amounts of crud and impurities and products of radiolytic decomposition.

3.25. Particular attention should be paid to assessing core conditions following startup and shutdown to ensure the following:

(a) The reactivity and control rod configurations are as predicted.
(b) Coolant and moderator flow rates are within specified limits.
(c) The reactor vessel (tank, pool) and core structural components and experimental devices are performing normally.
(d) The temperatures of coolant, moderator and core components are as expected.

3.26. The redundant and independent instrumentation for monitoring the relevant parameters should normally be arranged to achieve the following:

(a) To have adequate range overlap at all power levels from the source range to full power;

(b) To have suitable sensitivity, range and calibration for all operational states and, where appropriate, accident conditions;
(c) To facilitate the evaluation of core performance and the assessment of abnormal situations by operating personnel;
(d) To provide the highest sensitivity to changes in reactivity and to minimize the impact of localized changes of neutron flux.

3.27. Parameters such as coolant and moderator temperatures, coolant and moderator flow rates, neutron flux and, where appropriate, coolant and moderator pressures should be measured and displayed appropriately to the reactor operator. Where applicable, changes in the core due to refuelling and fuel burnup may necessitate changes in alarm levels and in safety system settings. For operation at reduced power levels or in the shutdown state, consideration should be given to the need to adjust the set points for alarm annunciation and/or the initiation of safety actions to maintain appropriate safety margins.

3.28. In many cases, the parameters that affect fuel behaviour are not directly measurable. In such cases, these parameters should be derived by analysis from measured parameters such as neutron flux, temperatures, pressures and flow rates. The derived values are used as a basic input for establishing OLCs. Parameters for use by the reactor operator should be given in terms of the values available in the control room from instrument indications or the display of derived values.

3.29. Methods and acceptance criteria should be established for assessing measured core parameters and correlating them with other parameters important to safety that cannot be measured directly, such as the internal temperatures of the fuel and cladding, and internal control rod pressures and temperatures in experiments. The effects and the safety implications of the irradiation of core material, core components, experimental devices and irradiation devices should be assessed. These assessments and correlations should be recorded, and they should form the basis for ensuring conformance with the OLCs and for taking appropriate corrective actions, if necessary.

3.30. The values of parameters such as those relating to chemical control and purity control should be derived either from direct measurements or from periodic analyses of samples of coolant, moderator or cover gas. The operating personnel should be regularly informed of the results of these analyses. To avoid specified values of such parameters being exceeded, operating personnel should be provided with instructions concerning the actions to be taken if these parameters tend to approach pre-established limits.

3.31. Suitable instrumentation should be provided and maintained for monitoring the core parameters, such as (a) core power, (b) flow rate and temperature of the coolant and moderator, and (c) efficiency of the means of shutdown of the reactor. The instrumentation to be used for core monitoring should be appropriately qualified in accordance with Requirement 29 of SSR-3 [1].

ENSURING FUEL INTEGRITY AT A RESEARCH REACTOR

3.32. Requirement 44 of SSR-3 [1] states:

> "**Research reactor core components and fuel elements and assemblies for a research reactor shall be designed to maintain their structural integrity and to withstand satisfactorily the conditions in the reactor core in all operational states and in design basis accident conditions.**"

3.33. The operating organization is required to ensure that fuel assemblies have been manufactured in accordance with design specifications (see para. 4.17 of SSR-3 [1]).

3.34. Prior to insertion or reinsertion, fuel assemblies should be inspected against established acceptance criteria to ensure that damaged fuel assemblies are not loaded into the core.

3.35. Fuel surveillance for the early detection of any deterioration that could result in an unsafe condition in the reactor core should be part of the OLCs and should be implemented through a programme of surveillance and in-service inspection in accordance with the recommendations provided in SSG-81 [3]. Fuel surveillance activities should be part of an overall surveillance programme and should include monitoring, checking, calibration, testing and inspection. The following items that are particularly relevant to core management and fuel handling should be covered by the surveillance programme:

(a) Protection and control systems (i.e. operability, actuation times and reactivity change rates).
(b) Core cooling systems, including the cooling of core components (i.e. flow rate, pressure, temperature, activity, conductivity and chemistry of the coolant). Subcritical assemblies might not need cooling for heat removal purposes; however, these provisions should be applied to the fluids contained within subcritical assemblies to preserve the fuel elements and avoid radioactive releases.

(c) Handling systems for fuel assemblies and core components.
(d) Degradation of fuel assemblies and other core components, such as dimensional changes, bowing, fretting and wear.

3.36. Routine monitoring is required in order to confirm the integrity of the fuel cladding (see para. 6.141 of SSR-3 [1]). In an open or pool type reactor (without a forced circulation system), this should be performed by monitoring the activity of airborne fission products. In a reactor core contained within an enclosure such as a reactor vessel, any breach of fuel cladding integrity should be detected by monitoring for fission products in the coolant or in off-gas from the coolant. In some cases, a detector located in the coolant flow is used to monitor for delayed neutrons. Appropriate methods should be established to identify any anomalous changes in airborne activity or coolant activity and to perform data analysis to determine the following (see also para. 7.80(b) of SSR-3 [1]):

(a) The nature and severity of fuel defects;
(b) The root causes of fuel defects;
(c) Corrective actions.

3.37. The monitoring of fuel integrity is required to be arranged so as to ensure that radiation exposures are as low as reasonably achievable (see para. 2.6 of SSR-3 [1]).

3.38. The level of fission product activity should be determined during the initial period of reactor operation following startup in order to provide a reference background level. This background level is caused by fissionable material remaining on the outside surface of the cladding from the manufacturing process and results in low level activity, often below the detectable range. Routine or continuous monitoring may be necessary to determine the need to revise the reference background level as the reactor operation evolves.

3.39. One indication of fuel assembly failure is an increase in fission product activity above the normal level. Monitoring of fission product activity in the coolant should be performed routinely by means of an on-line instrument and/or by measurement of the activity in samples. Identification of particular fission product radionuclides may be necessary to characterize fuel assembly failures.

3.40. If a fuel assembly failure is suspected, the failed assembly should be identified and removed from service before routine reactor operation is resumed. If necessary, limited operation of the research reactor may be performed to identify the failed assembly, and the cause of the failure is then required to be investigated in accordance with para. 7.80(b) of SSR-3 [1]. In special cases, this may involve the examination of the fuel assembly in a hot cell.

3.41. To ensure that corrective actions are taken for failed fuel assemblies, a failure contingency procedure should be established to address the following key elements:

(a) Action levels for investigation of a suspected fuel assembly failure;
(b) Measures to identify leaking fuel assemblies and to remove them from service;
(c) Measures to determine the cause of the loss of integrity of a fuel assembly;
(d) Measures to remedy the cause of damage to a fuel assembly;
(e) Inspection activities for fuel assemblies;
(f) Review of lessons learned to prevent failures arising from the same root cause in the future.

PROCUREMENT OF NEW FUEL AND DESIGN MODIFICATIONS AT A RESEARCH REACTOR

3.42. Approved procedures for the procurement of new fuel assemblies should be in conformance with the general procurement policy of the operating organization, as established in the management system (see Section 2). The procedures should include the following:

(a) Verification that current and approved specifications and drawings are being used;
(b) Verification that purchase orders specify the inspections to be performed by the operating organization at the fuel fabrication facility;
(c) Completion of all forms for the requisition of fissionable material;
(d) Provisions for the resolution of minor non-conformities in the fabricated fuel assembly or other core component.

Practical guidance concerning the procurement of research reactor fuel assemblies is provided in Refs [16, 17]. Recommendations on the procurement process for other core components are provided in SSG-24 (Rev. 1) [10].

3.43. If a fuel assembly of a new or modified design (e.g. an assembly containing low enriched uranium instead of high enriched uranium) is to be introduced into the core, the operating organization is responsible for ensuring that a safety analysis has been performed in accordance with the recommendations provided in

SSG-20 (Rev. 1) [9]. Prior to operating a core with more than one type of nuclear fuel, the operating organization should perform an additional safety analysis to ensure that the new or modified fuel assembly is compatible with existing fuel assemblies and that the core designer has access to all the relevant information. This safety analysis should be documented in an updated safety analysis report. The details of the new fuel assembly should be reflected in the OLCs and in other safety related documentation.

3.44. Feedback from experiments and from research and development programmes covering power ramp analysis (performed by means of tests or performed analytically), reactivity initiated accident tests and loss of coolant accident tests (analytical or global) performed during fuel qualification should be taken into consideration to demonstrate the behaviour of fuel of new designs under operational states and accident conditions.

3.45. The operating organization is responsible for ensuring that all necessary safety evaluations of new or modified fuel assemblies are performed and that a new fuel assembly meets the design criteria provided in volume 4 of Ref. [16]. Appropriate licensing documentation should be prepared for all new or modified fuel that is loaded (or reloaded) into the research reactor. This documentation should include the following:

(a) Information on the design of the fuel assembly and input data for the prediction and monitoring of core behaviour;
(b) Results of analyses and testing that were used to develop correlations for monitoring thermal margins;
(c) Verification of mechanical, thermohydraulic and neutronic limits for design compatibility;
(d) The safety analysis, including analysis of transients and performance under accident conditions.

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

(a) Testing the administrative routines, tools and equipment for handling the new nuclear fuel;
(b) Monitoring the performance of the new nuclear fuel, including corrosion effects;

(c) Gaining practical operating experience of using more than one type of nuclear fuel in the core.

3.47. When considering a new supplier, the operating organization should ensure that the supplier has the ability to meet the quality requirements for fuel assemblies. In particular, an analysis should be performed of all differences in the manufacturing process of the new supplier and all changes in fuel assembly parameters, irrespective of whether they are included in the specifications. An audit of the supplier's documentation relating to an individual fuel assembly may be an appropriate way to demonstrate the compliance of the supplied fuel assembly with the design intent.

REFUELLING PROCESS AT A RESEARCH REACTOR

3.48. Requirements for fuel handling and storage facilities are established in paras 6.195–6.200 of SSR-3 [1].

3.49. All fuel assembly movements and core alterations are required to be undertaken in accordance with approved operating procedures (see Requirement 78 of SSR-3 [1]). Throughout such fuel assembly movements and core alterations, the core integrity and reactivity are required to be monitored (see para. 7.82 of SSR-3 [1]) to prevent damage to core components and inadvertent criticality. Intermediate fuel assembly patterns should be no more reactive than the most reactive configuration considered and approved in the OLCs and should be verified during research reactor commissioning. There should be a method of checking that fuel assembly movements will not conflict with one another, and it should be possible to reverse fuel assembly movements if necessary.

3.50. The refuelling programme should include details of the core configuration and a schedule of movements of core components and experimental devices into and out of the reactor.

3.51. When designing a refuelling programme to provide sufficient reactivity to compensate for fuel burnup and the buildup of fission products, the safety objectives that are to be met throughout the lifetime of the research reactor, starting from the initial fuel loading, should include the following:

(a) Maintaining the neutron flux distribution and other core parameters (such as burnup and excess reactivity) within applicable OLCs;
(b) Providing an adequate shutdown margin.

3.52. Aspects that should be considered in the establishment and execution of a refuelling programme include the following, as appropriate:

(a) Fuel burnup, including fission density limits and consequential structural and metallurgical limitations;
(b) Temperatures of coolant and fuel cladding in relation to neutron flux distributions, flow patterns and neutron absorber configurations;
(c) Hold points defined in the refuelling programme and in power ascension following refuelling, at which specified checks, tests and verifications (e.g. for criticality) should be performed before proceeding with additional fuel assembly movements or power ascension;
(d) Use of prototypes and simulations to verify that procedures are correct and their execution is practicable and to familiarize operating personnel with the tasks they are expected to execute;
(e) Assurance of the mechanical capability of fuel assemblies to withstand reactor core conditions and refuelling operations, particularly for shuffling and reuse of irradiated fuel assemblies;
(f) Special considerations that necessitate restrictions on specific fuel assemblies, such as limitations on the burnup;
(g) Changes arising from the removal of failed fuel assemblies and the insertion of new fuel assemblies (e.g. changes in reactivity and local temperature);
(h) Positioning of unirradiated and irradiated fuel assemblies in the core, with account taken of reactivity, fuel enrichment and the buildup of fission products;
(i) The most limiting orientation of a fuel assembly, when its rotational and axial orientation is not specified or constrained, and the most reactive conditions created by experiments and irradiation programmes;
(j) The depletion of the neutron absorber in control rods and of burnable neutron absorbers;
(k) The highest reactivity worth of an individual control rod that could remain inoperable in the fully withdrawn position;
(l) Deviations of actual operating parameters from predictions based on calculations.

3.53. After refuelling, core conditions should be assessed before further power operation to verify that the OLCs, including shutdown margins, will be met throughout the operating cycle. Shutdown capability in accordance with Requirement 46 of SSR-3 [1] should be confirmed frequently by means of appropriate testing.

3.54. Checks, including independent verification, should be performed during and after a fuel reload to provide assurance that the research reactor core has been correctly configured. Additionally, physics tests should be performed after each reload, before or during startup, to verify the configuration and characteristics of the core and control rod reactivity worth throughout their operating range. Tests should include the following, as appropriate:

(a) Withdrawal and insertion of each control rod to check for operability;
(b) Checks of safety system settings and measurements of control rod drop times or injection of borated water;
(c) Measurement of the reactivity worth of control rods, experimental devices and irradiation devices;
(d) Demonstration that if the control rod with the highest reactivity worth is in the fully withdrawn position and movable experimental and irradiation devices are in their most reactive conditions, the core meets the OLCs for shutdown margin;
(e) Comparison of predicted and measured control rod configurations for reactor criticality in accordance with planned rod withdrawal sequences;
(f) In-core neutron flux mapping using either temporary or permanently installed in-core detectors;
(g) Comparison of measured and calculated neutron flux distributions and power distributions.

4. HANDLING AND STORAGE OF FRESH FUEL AT A RESEARCH REACTOR

FRESH FUEL MANAGEMENT AT A RESEARCH REACTOR

4.1. The safety objectives of fresh fuel handling at a research reactor are to prevent inadvertent criticality and to prevent physical damage to the nuclear fuel when it is being transported, stored or manipulated. Fuel assemblies are required to be protected against damage (see paras 6.198(c) and 7.81 of SSR-3 [1]), in particular damage that could affect the behaviour of the nuclear fuel in the core, for example by causing restriction of the coolant flow. See also the recommendations provided in IAEA Safety Standards Series No. SSG-27 (Rev. 1), Criticality Safety in the Handling of Fissile Material [18].

4.2. The principal activities in fresh fuel handling at a research reactor include receipt, transfer, inspection and storage, in accordance with administratively controlled procedures and engineering practices that are intended to meet the following objectives:

(a) To delineate physical boundaries within which new fuel assemblies are to be stored and subject to processes for material control and constraints on the criticality configuration;
(b) To meet administrative requirements and to provide technical instructions for inspection of fresh fuel assemblies, including actions to be taken with regard to damaged fuel.

4.3. Fuel handling procedures should emphasize the need to minimize mechanical stresses, to prevent scratches or other damage to the cladding, to avoid substances that could degrade the integrity of the cladding, and to ensure protection against theft and sabotage.

4.4. Handling of fresh fuel assemblies, either manually or by means of automated facilities, should only be performed with equipment specifically designed for that purpose. Operating personnel engaged in fuel handling should be appropriately trained and qualified and should work under the supervision of an authorized person. All activities relating to handling of fresh fuel are required to be performed in accordance with approved procedures (see para. 7.81 of SSR-3 [1]).

4.5. Fuel assemblies suspected to have been damaged during handling or storage should be quarantined and inspected. Procedures for identifying and dealing with failed fuel assemblies are required to be prepared (see para. 4.16).

4.6. When fresh fuel is handled manually, suitable protective equipment and clothing should be used to prevent the contamination of personnel and to prevent damage to, or contamination of, the fuel cladding.

4.7. If fuel assemblies are to be moved between buildings on the site, suitable and appropriately labelled packaging should be used to prevent damage to, or contamination of, the nuclear fuel. Routes for all fuel assembly movements should be kept as short and simple as possible. Vehicular traffic during the movement of fuel assemblies between buildings should be restricted.

4.8. Areas for the handling and storage of fresh fuel assemblies should be maintained under appropriate environmental conditions (e.g. appropriate conditions of humidity, temperature and clean air), and controls should be established to exclude chemical contaminants and foreign materials.

4.9. Handling and storage areas for fresh fuel should be secured against unauthorized access and unauthorized removal of nuclear fuel (see also Requirement 39 of SSR-3 [1]). A storage area should not be part of an access route to other operating areas.

4.10. The design is required to prevent damage to stored nuclear fuel from the inadvertent dropping of heavy loads (see para. 6.198(d) of SSR-3 [1]). Such loads should not be moved in the space above stored fresh fuel (in racks, storage canisters or lifting devices), and any exceptions to this should be justified.

4.11. Equipment used to check the physical dimensions of the fuel assemblies should be calibrated prior to first use and periodically recalibrated. Fuel handling equipment and associated systems should be checked periodically, and certainly before refuelling is commenced.

4.12. Requirement 58 of SSR-3 [1] states that “**The design for a research reactor facility shall include provisions for the safe handling and storage of fresh and irradiated fuel and core components.**” Manual and automated fuel handling equipment should be so designed that in the event of a failure during use fuel assemblies can be readily placed in a safe location.

4.13. Fresh fuel assemblies giving rise to higher radiation levels (e.g. fuel that contains reprocessed materials) should be handled in accordance with approved procedures specifically developed to reduce the exposure of operating personnel.

RECEIPT OF FRESH FUEL AT A RESEARCH REACTOR

4.14. Before fuel assemblies are received, the operating organization should ensure that a designated person (usually the safeguards officer or the reactor manager) is responsible for control of fuel assemblies on the site and that access to the fuel storage area is denied to unauthorized personnel.

4.15. Fuel assemblies should be received, unpacked and inspected against established acceptance criteria by trained and qualified personnel in accordance with approved procedures that include procedures for the identification of damaged fuel (see para. 7.81 of SSR-3 [1]). The receipt and unpacking of fresh fuel should take place in an area designed for fuel handling. An inspection programme for fresh fuel should be established to check the external appearance of fuel assemblies and to check for any damage sustained during transport. Inspection of fuel assemblies should include the comparison of specified parameters (e.g. dimensions) that might have been affected by transport or handling since the supplier's final inspection against those recorded in the fuel history dockets provided by the supplier. The fuel assembly identification number should be verified, and related documentation should be checked to confirm that the nuclear fuel received corresponds to what was ordered and conforms to design requirements (see para. 3.45).

4.16. The procedures for identifying and dealing with damaged or failed fuel should be reviewed if fuel assemblies of a new design are procured. Acceptance criteria for assessing damaged fuel should be prepared. A record should be made of any damage accepted by the examiner. Rejected fuel assemblies should be treated as non-conforming in accordance with the management system. The root causes of any failure are required to be investigated and corrective measures taken to prevent recurrence (see para. 7.80(b) of SSR-3 [1]).

4.17. Transport casks and packages should be checked to verify that they have been properly identified and are free from damage. The arrangements for the storage and identification of fresh fuel should be such as to eliminate unnecessary handling.

4.18. Inspections should not damage the fuel assembly (e.g. they should involve non-destructive testing methods such as neutron or gamma spectrometry techniques) and should not introduce any foreign material into the fuel assembly. The personnel inspecting the fresh fuel should identify any foreign material already present in the fuel assembly and should arrange for its removal in accordance with approved procedures.

4.19. If, following inspection, fresh fuel assemblies have to be repaired, the supplier of the fuel assemblies 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 performed in accordance with approved procedures and that no critical configuration is created. The regulatory body should be advised of such repairs.

STORAGE OF FRESH FUEL AT A RESEARCH REACTOR

4.20. Proper receipt, storage and handling facilities to accommodate the full consignment of fuel assemblies should be available on the site before any fresh fuel is delivered. If nuclear fuel of a new design is to be delivered, if fuel enrichment or density is changed (i.e. increasing the mass of ^{235}U) or if re-racking of a storage area is necessary, the validity of the criticality safety analysis in the safety analysis report should be reassessed. An adequate number of specified storage positions should be available to ensure the integrity of fuel assemblies and to prevent damage to them.

4.21. Physical and/or administrative measures should be taken to ensure that fuel assemblies are handled and stored only in authorized locations to prevent a critical configuration from arising.

4.22. A dry storage area for fresh fuel should be clear of any equipment, valves or piping for which periodic surveillance by operating personnel is necessary.

4.23. For storage systems that use fixed solid neutron absorbers, a surveillance programme should be established to ensure that the absorbers are installed and to verify that they retain their integrity and effectiveness.

4.24. When fuel assemblies are stored outside their containers, the ventilation system should prevent dust and other airborne particles from entering the fresh fuel storage area.

4.25. Drains in dry storage areas for fresh fuel assemblies should be properly maintained for the efficient removal of any water that enters to avoid flooding of the storage area, which might increase the risk of criticality.

4.26. Fire risks are required to be minimized by preventing the accumulation of combustible material in the storage area (see para. 7.85 of SSR-3 [1]). Instructions for firefighting personnel and instructions on the use of firefighting equipment suitable for use on fires involving fuel assemblies should be readily available. Personnel are required to be trained in fire response so as to be in a state of preparedness (see para. 7.85(d) and (e) of SSR-3 [1]). Approved procedures should be established to control the introduction of moderating material or oxidizers (e.g. water) or of diluting neutron absorbing media (e.g. borated water) into the fresh fuel storage area (this also applies to subcritical assemblies), so 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].

4.27. Unauthorized access to fresh fuel assemblies should be prevented from the time of their arrival on the site. Any fresh fuel storage area should be designated as an item control area in which only fuel handling activities take place.

4.28. Before the first fuel assembly is delivered to the fuel storage area, the relevant parts of the radiation protection programme should be implemented (see Requirement 84 of SSR-3 [1] and Requirement 24 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [20]).

5. THE REFUELLING PROGRAMME FOR A RESEARCH REACTOR

PREPARATION FOR REFUELLING OF A RESEARCH REACTOR

5.1. The refuelling process described in paras 3.48–3.54 should form the basis for a refuelling programme implemented by means of approved procedures that specify in detail the sequence of the operations to be performed. The procedures should specify the specific fuel assemblies 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 programme should also specify the following:

(a) The fuel assembly to be shuffled or unloaded, and its original position in the core;
(b) The new location of the fuel assembly, either in the core or in the storage area;
(c) The sequence for unloading and loading fuel assemblies and other components such as control rods;
(d) The checks to be performed at each stage.

5.2. Key refuelling operations should be verified and signed off by an authorized person other than the fuel handler. Special precautions need to be taken when performing a full core unload, if the core is to be reloaded, to ensure that fuel assemblies and other core components are returned to their correct positions and orientation, as applicable.

5.3. The steps necessary to prepare fresh fuel assemblies for use in the research reactor should be specified in approved procedures. Only approved nuclear fuel (see paras 3.32–3.41) should be loaded into the reactor core. An independent check by at least one other competent person should be performed to confirm that the core has been assembled correctly. In all refuelling steps, it should be ensured as far as possible that no foreign materials are introduced into the reactor.

5.4. A means of checking the condition of the nuclear fuel prior to its use should be provided to minimize the risk of inserting, into the reactor core, fuel that is damaged or not within the limits specified in the OLCs or in the supporting analysis in the safety analysis report.

5.5. Any equipment needed for core monitoring during the refuelling process should be tested during the preparation process to ensure that it is operating properly. Reliable means of three-way[5] communication between the fuel handling personnel and the control room personnel should be available at all times.

LOADING FUEL AND CORE COMPONENTS AT A RESEARCH REACTOR

5.6. When a fuel assembly is moved from storage, it should be identified and checked against the approved refuelling programme. Arrangements should be made to ensure as far as possible (e.g. through an independent check by personnel not directly involved in the loading operation) that the fuel assembly has been loaded into the specified position in the core and correctly positioned (and, where relevant, with the specified orientation). Any subcriticality checks to be performed during refuelling should be specified in the refuelling programme.

5.7. Fuel handling procedures may be simpler when a reactor core is being loaded for the first time (i.e. because the fuel assemblies and core components have not yet been irradiated); however, refuelling procedures and the management system should still be followed. All fuel handling tools and equipment, whether for manual or automated handling, should undergo commissioning tests and pre-use checks prior to use with fuel assemblies. SSG-80 [2] provides further recommendations on these aspects. Procedures should be verified, and fuel handlers should be

[5] The following three steps establish three-way communication: (a) clear delivery of the message by the sender; (b) acknowledgement and repeat back by the receiver that the message is clearly understood; and (c) confirmation of the acknowledgement by the sender. This final step is also the final command to proceed to the action stated in the message.

trained using mock-ups, dummies or test fuel assemblies. Approved procedures should be followed to ensure that tools and foreign materials have been removed from the vicinity of the core before research reactor operation is commenced. Dummy or test fuel assemblies should be clearly distinguishable, even when placed in the core.

5.8. Core components (e.g. instrumentation, coolant flow orifice plate, plugs, control rods, neutron absorbers, fixtures for experimental or irradiation devices) that form part of, or are attached to, a fuel assembly should be inspected and checked as part of the refuelling procedure in accordance with the management system. Any safety aspects relating to neutron sources and core components that have not been taken into account in the fuel loading plan are required to be considered before these assemblies and components can be loaded into the reactor core (see para. 7.80(a) of SSR-3 [1]). Recommendations on tests that should be completed prior to the first core loading are provided in SSG-80 [2].

5.9. Procedures are required to be prepared to control the movement of any core component into or out of the core (see para. 7.81 of SSR-3 [1]). Checks should be incorporated, where possible, to confirm that the fuel has been satisfactorily inserted.

5.10. When a significant quantity of nuclear fuel is being loaded or a core component (e.g. control rod, neutron absorber, experimental or irradiation device) is being moved into a shutdown reactor, the degree of subcriticality should be monitored to ensure that an unanticipated reduction in the shutdown margin and an inadvertent criticality are avoided. Tests to verify the shutdown margin may be performed as the loading progresses.

UNLOADING FUEL AND CORE COMPONENTS AT A RESEARCH REACTOR

5.11. Fuel assemblies and core components should be unloaded in accordance with the approved refuelling programme. Adequate cooling of the fuel assemblies and core components is required to be ensured in all steps of the programme (see Requirement 7 of SSR-3 [1]).

5.12. The identification of the fuel assemblies or core components should be checked against the refuelling programme each time one is moved to a new location. Any error found in either the original loading or the reloading should be documented and reviewed by the appropriate personnel to ensure that appropriate corrective actions are taken prior to resuming operations.

5.13. The radiation protection measures to be taken when handling unloaded nuclear fuel, core components and materials and when undertaking disassembly operations should be specified in the refuelling procedures. There should be a clear policy to use only suitable and designated areas for storing (even briefly) irradiated or contaminated items in order to avoid the spread of contamination or undue radiation exposure.

5.14. If any damage is suspected, unloaded fuel assemblies and core components should be examined before storage. Discovery of damage to fuel assemblies or core components may necessitate the examination of adjacent components. Any repairs should be made using proven techniques, in accordance with approved procedures and with reference to the manufacturer of the fuel assembly.

5.15. A fuel assembly that is known to have failed should be quarantined to prevent its subsequent inadvertent use and should be suitably treated to minimize contamination of the storage facility and to permit compliance with the applicable requirements for transport established in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [21], when it is subsequently shipped off the site. A fuel assembly that is suspected to have failed should be regarded as failed fuel unless a thorough check shows that it is intact.

5.16. Fuel storage racks should be kept within specified tolerances to ensure that fuel assemblies are not distorted.

HANDLING FUEL AND CORE COMPONENTS AND TESTING CONTROL RODS AT A RESEARCH REACTOR

5.17. Handling of fuel and core components should be performed in accordance with approved procedures that should include the necessary precautions to ensure safety. Aspects that should be considered include reactivity status, component integrity, heat dissipation and radiation protection including shielding. Examples of issues to be considered in relation to the handling of fuel assemblies and other core components include the following:

(a) Criticality, for example arising from errors made in manipulating reactivity control devices;

(b) Physical damage to a fuel assembly resulting from the bumping or dropping of components;
(c) Damage to a fuel assembly due to lack of proper cooling;
(d) Distortion, swelling or bowing of fuel assemblies;
(e) Exposure of operating personnel to radioactivity from components or material released during handling.

5.18. Recommendations on additional considerations that apply to the initial core loading, initial criticality and commissioning of a research reactor are provided in SSG-80 [2].

5.19. Considerations for the handling of fuel and core components vary substantially depending on the type of research reactor and fuel assembly design, as well as on power densities and operating histories. Typical considerations include the following:

(a) Establishment of controls and supervision for radiation protection purposes;
(b) Availability and operability of appropriate tools and equipment, including, if necessary, devices for viewing the work;
(c) Confinement and containment integrity during the handling of fuel assemblies and core components;
(d) Operability of the ventilation system;
(e) Reliability of the source of electrical power;
(f) Operability of the startup range neutron flux detectors and related alarms;
(g) Insertion of control rods into the core and disconnection to render them inoperable during refuelling operations with the reactor core in shutdown condition;
(h) Specified minimum time between shutdown and commencement of the movement of fuel assemblies and core components;
(i) Specification of the safety instrumentation needed for operation and of the frequency of checks;
(j) Availability of appropriate cooling and emergency cooling;
(k) Implementation of appropriate procedures to prevent foreign materials from being introduced into the reactor;
(l) Measures to prevent any unnecessary movement of loads over the reactor core;
(m) Adequacy of communication links between the control room and the core loading area;
(n) Clear delegation of authority;

(o) A final check that the fuel assemblies and core components have been correctly loaded and properly positioned in (or fixed into) the core grid (see also para. 5.6);
(p) Establishment of contingency procedures and emergency procedures for fuel handling incidents.

5.20. Testing and inspection of control rods and control rod drive mechanisms should be performed frequently enough to enable verification of reliable control rod operation and discovery of at least the following anomalies in a timely manner:

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

6. HANDLING AND STORAGE OF IRRADIATED FUEL AT A RESEARCH REACTOR

6.1. Fuel assemblies that have been used in the reactor will be highly radioactive and will contain radioactive actinides and fission products that are retained in the irradiated fuel assemblies. (Subcritical assemblies are unlikely to include significantly irradiated fuel, and therefore some recommendations relating to handling and storage of irradiated fuel might not apply.) The safety objectives associated with the handling and storage of irradiated fuel assemblies are as follows:

(a) To ensure subcriticality at all times;
(b) To prevent physical damage to fuel assemblies or to the fuel elements;
(c) To maintain an environment that does not degrade the integrity of the fuel cladding;
(d) To ensure an adequate rate of heat removal;
(e) To ensure that radiation exposures and the release of radioactive substances during the handling of irradiated fuel will be kept as low as reasonably achievable.

6.2. To ensure that the integrity of the fuel assemblies and subcriticality are maintained, irradiated fuel should be handled, stored and inspected in approved facilities by trained and competent personnel and with tools and equipment certified for this purpose.

6.3. All movement, handling, storage and inspection of irradiated fuel are required to be performed in accordance with approved procedures (see para. 7.81 of SSR-3 [1]). The completion of key tasks should be verified and signed off by authorized personnel.

6.4. Equipment used for the movement of irradiated fuel assemblies should be qualified and tested before use.

6.5. A system should be established to account for the radionuclide inventory and, if relevant, the decay heat of the irradiated fuel.

6.6. Measures should be implemented to control the spread of contamination in order to ensure a safe working environment and to prevent unacceptable releases of radioactive material (see also para. 6.100 of SSR-3 [1]). For this purpose, dedicated equipment and procedures should be provided to cope with damaged or leaking fuel. Sealable containers of an approved design for leaking fuel assemblies should be readily available.

6.7. Shielding, as necessary, is required to be provided around all areas in which irradiated fuel may be placed (see para. 6.199 of SSR-3 [1]) to ensure that occupational exposure from external radiation from nuclear fuel, fission products and activated materials is kept as low as reasonably achievable.

6.8. Handling and storage areas for irradiated fuel (and for fuel handling tools used to remove fuel assemblies) should be secured against unauthorized access or unauthorized removal of fuel assemblies (see also Requirement 39 of SSR-3 [1]). Core components intended to be handled or stored in areas for irradiated fuel should be managed in accordance with approved procedures.

6.9. Appropriate procedures should be established to manage anticipated operational occurrences, design basis accidents and design extension conditions without significant fuel degradation in the handling and storage of irradiated fuel. These procedures should cover events arising within the facility (e.g. criticality, loss of heat removal, dropped loads, internal fires and floods, operator errors, failures of safety systems), events external to the facility (e.g. seismic events, flooding, extreme meteorological conditions, loss of off-site electrical power, and all credible combinations thereof), and security related incidents (including physical security and computer security; see paras 2.18(h) and 2.19).

STORAGE OF IRRADIATED FUEL AT A RESEARCH REACTOR

6.10. Paragraph 6.195 of SSR-3 [1] states:

> "The design shall include provisions for safely storing a sufficient number of spent fuel elements and irradiated core components. These provisions shall be in accordance with the programmes for core management and for removing or replacing fuel elements and core components."

6.11. Approved procedures should be used to ensure that the irradiated fuel assemblies are stored only in configurations that have been assessed and approved. In analyses for fuel storage, all fuel types used in the facility and the maximum reactivity worth of the irradiated fuel assemblies in the storage facility during its lifetime should be considered. Recommendations on the storage of spent nuclear fuel are provided in IAEA Safety Standards Series No. SSG-15 (Rev. 1), Storage of Spent Nuclear Fuel [22].

6.12. Conformance with approved configurations and, if necessary, requirements for neutron absorbers (see para. 6.198(a) of SSR-3 [1]) in the storage facility should be ensured. Neutron absorbers may be fixed absorbers (e.g. borated plates) or, for pool storage, dissolved neutron absorbers in the pool water. A surveillance programme should be established to ensure the integrity and effectiveness of any neutron absorbers used for irradiated fuel storage. Suitable measures, including administrative procedures, for ensuring subcriticality should be implemented.

6.13. Paragraph 6.199 of SSR-3 [1] states that "Handling and storage systems for irradiated fuel shall be designed to permit adequate heat removal and shielding in operational states and accident conditions."

6.14. 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 heating, ventilation and air-conditioning systems should be ensured.

6.15. For wet storage facilities, it should be ensured that the bulk temperature of pool water as well as the variations in and the rates of change of temperature are maintained within acceptable limits and that the pool make-up capacity is sufficient to compensate for evaporation. The composition of the cooling medium should be controlled to prevent deterioration of the fuel cladding for all postulated conditions of irradiated fuel.

6.16. For wet storage facilities, the chemical and physical characteristics of the pool water should be maintained in accordance with the OLCs so as to achieve the following:

(a) To avoid corrosion of irradiated fuel, core components and structures in the pool by maintaining suitable pH values and other chemical, biological and physical conditions as applicable (e.g. halogen ion concentrations, conductivity);
(b) To avoid crystallization of dissolved boron by maintaining pool temperatures above a minimum level;
(c) To reduce contamination and radiation levels in the pool area by limiting water evaporation and radioactivity in the water;
(d) To facilitate fuel handling in the pool by maintaining water clarity (i.e. by the removal of impurities and suspended particles) and providing adequate underwater illumination;
(e) To prevent the dilution of dissolved neutron absorbers in pools where these are used for criticality control.

6.17. To avoid damage to irradiated fuel assemblies stored in the storage pool, the movement of heavy objects over stored fuel (e.g. by using a crane or similar device) should be prohibited unless subjected to a safety analysis and specifically authorized on a case by case basis (see also para. 6.198(d) of SSR-3 [1]). All lifting should be restricted to the minimum height necessary to complete the operation safely. Lifting devices (e.g. cranes) should be checked periodically to ensure correct operation.

6.18. Storage areas for irradiated fuel should be subject to access control for radiation protection and for nuclear security purposes. Access should be limited to authorized personnel, and provision should be made for the continuous monitoring of access.

6.19. For wet storage facilities, examples of the precautions that should be taken to optimize protection and safety include the following:

(a) The pool water should be maintained between specified levels, leakage should be monitored, and level alarms should be tested.
(b) Radiation monitors should be checked for operability and calibration to ensure that they provide an alarm if the radiation level reaches the alarm setting.

(c) Radiation levels at the water surface should be controlled by the use of approved procedures and tools to ensure that the fuel assembly 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 the OLCs (see also para. 6.211 of SSR-3 [1]).
(e) Adequate means of communication between the pool storage area and the control room should be provided.
(f) Training, proper supervision and work control procedures (with the use of work permits) should be provided.
(g) Dose history records and medical records of personnel should be maintained in accordance with Requirement 25 of GSR Part 3 [20].

6.20. For dry storage or storage under liquids other than water, appropriate safety procedures should be established.

6.21. Paragraph 6.196 of SSR-3 [1] states that "The design shall include provisions to unload all fuel from the core safely at any time." For some research reactors, it may be important to safety to retain sufficient storage capacity to accommodate the fuel assemblies from the reactor and the control rods at the same time.

6.22. A policy should be adopted for the exclusion of foreign materials from irradiated fuel assemblies in storage (see also para. 7.9(r) of SSR-3 [1]). Approved procedures should be established to control the use of certain materials, such as loose parts or transparent materials that cannot be seen underwater.

6.23. Plans are required to be prepared for dealing with damaged or leaking fuel assemblies (see para. 7.81 of SSR-3 [1]), and appropriate storage arrangements for suspect or damaged fuel elements are required to be provided (see para. 6.198(e) of SSR-3 [1]). These arrangements can include the following:

(a) Storing damaged or leaking assemblies separately from other irradiated fuel;
(b) Providing containers capable of retaining a severely damaged assembly and any fragments while permitting adequate cooling, and providing space in which to store the containers;
(c) Providing containers for the storage of radioactive or contaminated equipment or parts from failed fuelled experiments, either for long term storage or for transport off the site.

6.24. To track the performance of fuel assemblies in the core and to predict future behaviour, a programme for the inspection of irradiated fuel assemblies should be established, in accordance with Requirement 77 of SSR-3 [1]. This is especially important when the unloaded fuel assembly is to be reused. The results of the inspection are also important in ensuring the integrity of the fuel assembly that is ultimately dispatched, investigating the root causes of a fuel assembly leakage and providing feedback to the supplier of the fuel assemblies. Examples of possible attributes of such an inspection programme are as follows:

(a) Selection of fuel assemblies to be tracked and examined periodically throughout their time 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 test assemblies for testing new fuel assembly designs and for increasing burnup, and a follow-up programme for the inspection of such fuel in hot cells to study structural behaviour;
(c) Arrangements for the feedback and exchange of information with the supplier of the fuel assemblies.

6.25. Inspections should be performed in appropriate locations with equipment and procedures designed for the purpose. The results should be recorded and compared with established acceptance criteria.

7. HANDLING AND STORAGE OF CORE COMPONENTS AND NEUTRON SOURCES AT A RESEARCH REACTOR

7.1. Aspects that should be considered in the handling and storage of unirradiated core components include preventing damage, ensuring cleanliness and preventing radioactive contamination. These aspects should be taken into account in the design of handling tools for core components (including reactivity control devices, neutron sources, dummy fuel, reflectors, fuel channel instrumentation and flow restrictors, and experimental devices).

7.2. An adequate number of specified storage positions should be used for the storage of core components, in particular irradiated core components, and other items such as storage containers or transport casks or packages used in conjunction with core components.

7.3. All new core components should be visually examined for physical damage before their insertion into the core. Dimensional and functional checks should be performed to ensure that components are suitable for their intended function.

7.4. 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 (see also para. 7.84 of SSR-3 [1]).

7.5. Core components might become highly radioactive during operation of the research reactor. For irradiated core components, the following should be considered:

(a) Irradiated core components should be stored only in special locations in the storage area that are designed for the purpose.
(b) Adequate cooling should be provided.
(c) Access should be limited, and shielding for radiation protection should be provided.
(d) The material of the core component and the storage medium should be compatible.
(e) A core component that is to be reused or that needs to be retrievable for other reasons should be accessible.
(f) Where inspection of irradiated core components is necessary, interlocks should be provided, and other appropriate measures should be taken to ensure occupational exposure is as low as reasonably achievable.
(g) Means to transfer irradiated core components into suitable transport casks or packages should be provided where necessary.

7.6. In addition to ensuring sufficient storage capacity for core components, appropriate arrangements should be provided for the storage and use of handling tools and of other tools and equipment necessary for the disassembly and surveillance of core components.

7.7. Where appropriate, a programme should be established for the surveillance and maintenance of core components. Checks should be made for physical changes, such as bowing, swelling, corrosion, wear and creep. This programme should include examination of components to be returned to the core for further service and examination of discharged components to detect any significant degradation that has occurred during service. Maintenance programmes should include procedures to prevent the introduction of foreign materials into the reactor.

7.8. Adequate arrangements should be made for the clear identification of all neutron sources at the research reactor site, and administrative measures for their control should be implemented. Neutron sources should be adequately shielded and should be handled in accordance with approved procedures. Contamination checks should be performed following the receipt of transport packages containing neutron sources. The transport packages for neutron sources should be clearly marked in accordance with the requirements established in SSR-6 (Rev. 1) [21].

8. PREPARATION OF FUEL FOR DISPATCH FROM A RESEARCH REACTOR

8.1. Fuel assemblies should be removed from the research reactor only in accordance with an authorization that identifies the fuel assembly type, its irradiation history, its destination and the controls to be applied during its handling.

8.2. Preparation of fuel for dispatch may include cutting off non-fuelled end pieces so that the cropped fuel assembly will fit into the transport cask or package or to reduce the amount of non-fuelled material sent for further disposition. Such work is required to be performed following approved procedures (see para. 7.81 of SSR-3 [1]). The operating personnel who perform such activities are required to receive appropriate training in accordance with Requirement 70 of SSR-3 [1]. Supervision and monitoring should be provided as part of the radiation protection programme established and implemented in accordance with Requirement 84 of SSR-3 [1].

8.3. The type of transport cask or package should be selected in accordance with the fuel assembly to be loaded. Such casks or packages are required to be approved by the competent authority for the transport of radioactive material, in accordance with section VIII of SSR-6 (Rev. 1) [21]. This approval takes into account the fuel type; the number of fuel assemblies; the content of the fissile material (to ensure criticality safety); and the burnup, irradiation history and cooling time (to ensure that the radiation levels and decay heat levels remain within the specified limits for the cask or package). If the cask or package includes removable neutron absorber curtains or similar devices, procedures should be established to ensure that these are put in place before fuel assemblies are placed in the cask. The cask or package is also required to be marked and labelled in accordance with paras 530–544 of SSR-6 (Rev. 1) [21].

8.4. Procedures should be established for the preparation of the transport cask or package for transport off the site. The procedures should be followed to ensure, in particular, that the transport cask or package is properly loaded, closed and sealed and has adequate cooling capability and that radiation levels and contamination levels meet the requirements for the transport of radioactive material (see paras 501–503 of SSR-6 (Rev. 1) [21]). Other approved procedures for the preparation of the cask or package may be also necessary (e.g. procedures for vacuum drying, in which drying times, drying temperatures and off-gases are to be monitored). Additionally, approved procedures should be followed to ensure that the equipment necessary for handling the transport cask or package is available, has been functionally tested and is of proven reliability.

8.5. Procedures should include techniques such as the use of checklists requiring approvals and countersignatures for important hold points to ensure that the fuel assemblies have been properly loaded into the transport cask or package. Procedures should include the generation of records and transport documents.

8.6. The transport vehicle together with the transport cask or package should be checked for compliance with the requirements established in SSR-6 (Rev. 1) [21], including those for cask or package tie-down, vehicle placarding, and external contamination and radiation levels, before its dispatch from the site.

8.7. A cask or package that has previously been used should initially be assumed to contain radioactive substances, and contamination levels and radiation levels should be checked upon arrival at the research reactor site. If the contamination levels and radiation levels exceed specified values, an investigation should be made to discover the cause and to determine the corrective actions to be taken.

8.8. Before a previously used and supposedly empty transport cask is opened, radiation monitors with alarms should be checked to be operative, and suitable measures should be taken (e.g. opening the casks underwater) to prevent accidental exposure of personnel if radioactive material of significant activity has remained in the cask.

8.9. Additional requirements for the safe transport of radioactive material are established in SSR-6 (Rev. 1) [21].

9. DOCUMENTATION FOR CORE MANAGEMENT AND FUEL HANDLING AT A RESEARCH REACTOR

9.1. For the safe operation of a research reactor, the operating organization should have adequate information on the fuel assemblies, core parameters and 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. Information obtained during commissioning and subsequent operation should be evaluated as it becomes available and should be retained.

9.2. Paragraph 7.84 of SSR-3 [1] states that "A comprehensive records system shall be maintained in compliance with the management system to cover core management and the handling and storage of fuel, and core components." This records 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 assemblies and of activities relating to safety throughout the operating lifetime of the research reactor.

9.3. Typical records important to core management and the handling of fuel and core components include the following, as appropriate:

(a) The design basis, material properties and dimensions of the core and core components;
(b) Operational records for the facility;
(c) Data relating to installation tests and commissioning tests and records of special operating tests for fuel assemblies and core components;
(d) Core operating history (e.g. hourly logs of parameters such as temperature and flow rate);
(e) Power levels and time at power;
(f) Reactivity balance and critical configuration during startup;
(g) In-core neutron flux measurements;
(h) Refuelling patterns and schedules;
(i) Location of each fuel assembly and core component throughout its time on the site;
(j) History of burnup for each individual fuel assembly;
(k) Data on failures of fuel assemblies and core components;
(l) Results of examinations of fuel assemblies and core components;
(m) Status, repair history, modifications and test results of handling equipment used for fuel assemblies and core components;
(n) Coolant and moderator inventories, chemical quality and impurities;

(o) Records relating to core management (e.g. calculation notebooks, computer code descriptions);
(p) Computer calculations of core parameters, power and neutron flux distributions, isotopic changes and additional data considered important to fuel assembly performance;
(q) Comparisons of test results and validation of computational methods.

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Annex

REASONS FOR CORE MANAGEMENT AT A RESEARCH REACTOR

A–1. The core of a research reactor contains fuel assemblies, a moderator, reflectors, reactivity control devices, neutron absorbers and experimental devices. In many cases, these components are modular and are placed in prescribed locations on a grid plate to achieve an operational core that meets the needs of the current experimental programmes while ensuring compliance with the operational limits and conditions.

A–2. Core management is intended to accommodate the changes to the core brought about by modifications, for example the following:

(a) Fuel assembly replacements to compensate for burnup or radiation fluence limitations while maintaining core configuration;
(b) Fuel additions to compensate for burnup that modify the core configuration (e.g. increasing the core size through the addition of fuel assemblies);
(c) Reflector modifications to compensate for burnup (e.g. the insertion of a more efficient reflector to replace the existing reflector);
(d) Replacement of reactivity control devices;
(e) Removal of experimental devices following completion of an experiment;
(f) Insertion of new experimental devices (e.g. a neutron flux trap in the centre of the core);
(g) Installation of new core components (e.g. fuel and reflector assemblies or reactivity control devices) with new characteristics.

A–3. In some research reactors with a fixed core configuration for fuel, reflectors, reactivity control devices and experimental devices, core management may consist exclusively of compensation for burnup or lifetime radiation fluence limitations.

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