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Core Management and Fuel Handling for Research Reactors

Safety Guide

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IAEA

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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''.

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CORE MANAGEMENT AND FUEL HANDLING FOR RESEARCH REACTORS

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FOREWORD

by Mohamed ElBaradei
Director General

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

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

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was developed within the framework of the research reactor safety programme of the IAEA. It recommends how to meet the safety requirements for core management and fuel handling that are presented in paras 7.65–7.70 of the Safety of Research Reactors [1]. It is related to the Safety Guide on The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors [2], which identifies core management and fuel handling as two of the various important activities to be performed by the operating organization. These activities are related to the prevention of criticality accidents, with reference to Principle 8 of the Fundamental Safety Principles [3]: "Prevention of accidents: All practical efforts must be made to prevent and mitigate nuclear or radiation accidents." This principle states that: "The most harmful consequences arising from facilities and activities have come from the loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or other source of radiation."

OBJECTIVE

1.2. The purpose of this Safety Guide is to provide recommendations on meeting the safety requirements for core management and fuel handling at research reactors, on the basis of international good practices. This Safety Guide addresses those aspects of core management activities that should be performed in order to allow optimum reactor core operation and reactor utilization for experiments, without compromising the limits imposed by the design safety considerations relating to the fuel assemblies and the reactor as a whole. In this publication, 'core management' refers to those activities that are associated with the fuel assemblies, management of core components[1] and

[1] Core components are the elements of a reactor core, other than fuel assemblies, that are used to provide structural support of the core construction, or the tools, devices or other items that are inserted into the reactor core for monitoring, flow control or other technological purposes and are treated as core elements. Core components include experimental devices that may be fixed in the core (e.g. flux trap and test loop components, cold and hot neutron sources, and bulk samples for irradiation). Other experimental devices may be movable (e.g. irradiation baskets, small samples for irradiation).

reactivity control. ‘Fuel handling’ refers to the movement, storage and control of fresh and irradiated fuel, whether manually or by means of automated systems. This Safety Guide is intended for use by operating organizations, regulatory bodies and other organizations involved in the operation of research reactors.

SCOPE

1.3. The recommendations and guidance provided in this Safety Guide are intended to be applicable to research reactors having a limited hazard potential for the public. The publication describes the safety objectives, the tasks that should be performed to meet these objectives and the activities that should be undertaken to perform these tasks. The recommendations and guidance provided in the Safety Guide on Core Management and Fuel Handling for Nuclear Power Plants [4] have been reviewed and some of the best practices, where appropriate, have been adapted to suit the differences in hazard potential and complexity of systems between nuclear power plants and research reactors.

1.4. Additional guidance that is beyond the scope of this Safety Guide may be necessary for research reactors of higher power levels and specialized reactors (e.g. homogeneous reactors[2] or fast neutron reactors[3]). The recommendations and guidance provided for power reactors in Ref. [4] may be more suitable for such reactors (see also para. 1.9 of Ref. [1]).

1.5. Since the primary reason for operating a research reactor is its utilization, other recommendations for core management in this Safety Guide concern 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. This should be useful at those research reactor facilities that are being converted to use low enriched uranium (LEU) instead of high enriched uranium (HEU) [5].

1.6. Guidance on fuel handling covers: receipt of fresh fuel assemblies; storage and handling of fuel assemblies and other core components; inspection

[2] A homogeneous research reactor uses fuel in the form of a solution of fissile material.

[3] In fast neutron research reactors, the fission chain reaction is sustained by fast neutrons.

of fuel assemblies; loading and unloading of fuel assemblies and core components; inspection of irradiated fuel; insertion and removal of other reactor materials, either manually or by means of automated systems; preparation of fuel assemblies for shipment; and loading of a transport container with irradiated fuel.

1.7. The scope of this Safety Guide does not include guidance on transport safety or safety precautions for transport beyond the site or the off-site storage and ultimate disposal of irradiated fuel assemblies and core components.

1.8. Aspects of fuel accounting not directly related to nuclear safety are not considered in the scope of this Safety Guide; thus, safeguards aspects are not included.

1.9. 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 publication and reference should be made to the sections on design in Ref. [1]. Similarly, the design and installation of a new experimental facility that has major safety significance or off-site hazard potential is beyond the scope of this Safety Guide.

1.10. Low risk research reactors having a power rating of up to several tens of kilowatts and critical assemblies may need a less comprehensive core management and fuel handling programme than that outlined here. Low power reactors require infrequent core adjustments to compensate for burnup. They operate with substantial margins to thermal limits, allowing the consideration of a broad envelope of acceptable fuel loading patterns in the initial safety analysis in lieu of core specific calculations. While all recommendations in this Safety Guide should be considered, some may not apply to these low power level reactors. For these reasons, the recommendations provided in this Safety Guide should be graded[4] for applicability to a particular research reactor (see Ref. [1], paras 1.11–1.14).

1.11. Examples of a graded approach pertaining to reactor modification (e.g. core management) and new experiments are provided in Ref. [6] as follows:

[4] The recommendations should be graded, for example, by considering — using sound engineering judgement — the safety and operational importance of the topic, and the maturity and the complexity of the area involved.

(a) Paragraphs 305–326 of Ref. [6] discuss a four category system for the treatment of proposed reactor modifications and new experiments and classify them according to their hazard potential into four groups:
   (i) Changes that could have major safety significance;
   (ii) Changes that could have a significant effect on safety;
   (iii) Changes with apparently minor effects on safety;
   (iv) Changes having no effect on safety.

(b) Annex I of Ref. [6] discusses a two category system based on the identity of the approving authority (i.e. regulatory body approval or local approval);

(c) Annex I of Ref. [6] also discusses a multi-category system based on the potential radiological hazard such as:
   (i) Off-site hazard potential;
   (ii) On-site hazard potential only;
   (iii) No hazard potential beyond the reactor hall;
   (iv) No hazard potential.

Reference [6] describes for each of these categories the level of stringency that should be associated with the design and analysis, construction, commissioning, documentation, review and final approval for modifications and changes.

STRUCTURE

1.12. This Safety Guide consists of ten sections and one annex. Sections 2 and 3 provide recommendations on a management system for core management and fuel handling and on the core management programme respectively. Section 4 identifies the 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 deals with the handling and storage of core components, in particular, those that have been irradiated. Section 8 provides general recommendations on the preparatory arrangements for the dispatch of fuel assemblies from the site. Section 9 provides recommendations on administrative and organizational arrangements for core management, and Section 10 on general aspects of documentation.

1.13. The annex presents a brief discussion of the reasons why core management is necessary in some research reactors.

2. MANAGEMENT SYSTEM FOR CORE MANAGEMENT AND FUEL HANDLING

GENERAL

2.1. A documented management system that integrates safety, health, environmental, security, quality and economic objectives for the research reactor project should be put in place. The management system documentation should describe the system that controls the development and implementation of all aspects of the research reactor project, including core management and fuel handling. The management system (or parts thereof) should be submitted to the regulatory body for approval as required, in accordance with national regulations. The management system should include four functional categories: management responsibility; resource management; process implementation; and measurement, assessment and improvement. In general:

(a) Management responsibility includes providing the means and support needed to achieve the organization's objectives;
(b) Resource management includes measures to ensure that the resources essential to the implementation of strategy and the achievement of the organization's objectives are identified and made available;
(c) Process implementation includes those actions and tasks needed to achieve quality;
(d) Measurement, assessment and improvement provide an indication of the effectiveness of management processes and work performance.

Requirements and recommendations and guidance on the management system are provided in Ref. [1], paras 4.5–4.13, and Refs [7, 8].

2.2. As a part of the management system, a management system for core management and fuel handling should be established and put into effect by the operating organization early in the research reactor project. The system should be applied to all items and processes important to safety and should include the means of establishing controls over core management and fuel handling activities to provide confidence that they are performed in accordance with established requirements. The roles and responsibilities of personnel involved in core management and fuel handling should be defined in the management system (see also Section 9 of this Safety Guide). In establishing the system, a graded approach based on the relative importance to safety of each item or process (e.g. core configuration, critical experiments) should be adopted.

2.3. The objective of the management system is to ensure that the facility meets the requirements for safety as derived from:

(a) The requirements of the regulatory body;
(b) The design requirements and assumptions made in the design;
(c) The safety analysis report (SAR);
(d) The operational limits and conditions (OLCs) (see Ref. [9]);
(e) The administrative requirements for reactor management.

The management system should support the development and enhancement of a strong safety culture in all aspects of the core management and fuel handling programmes.

2.4. The management system for core management on the site should include procurement activities and should be extended to include suppliers. The operating organization should ensure that the manufacturers and designers have acceptable management systems and should ensure through audits that they comply with the integrated management system of the research reactor operating organization.

MANAGEMENT RESPONSIBILITY

2.5. The core arrangements and core components, including experimental devices, should be determined during the design stage of the reactor. However, it may become necessary to change the core and core components during the operational lifetime of the reactor because of the need to change fuel or becouse of changing experimental requirements (see the annex). This may lead to a corresponding change in the handling requirements for fuel and core components. In such cases, pertinent information from designers, manufacturers and other operating organizations should be used.

2.6. Successful implementation of the core management programme requires 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 all applicable regulatory requirements;
(f) Addressing the requirements of the OLCs;

(g) Availability and operability of special tools and equipment;
(h) A satisfactory working environment;
(i) Implementation and execution of the required inspections and tests.

2.7. The operating organization has the responsibility to prepare and issue procedures and specifications for the procurement, inspection, loading, utilization, unloading, storage, movement and testing of fuel and core components. Documents such as the core management programme, procedures, specifications and drawings should be prepared, reviewed, updated, approved, issued, validated as required, and archived.

2.8. There should be a designated person responsible and accountable for core management and fuel handling, including: developing and documenting the process; monitoring the performance of the process; ensuring that the staff are competent; and evaluating the impact of the process upon safety. This person is usually the reactor manager. In any case, the reactor manager should participate in the core management and fuel handling activities by means of:

(a) Frequent personal contact with core management and fuel handling staff, including the oversight of work in progress;
(b) Establishing and implementing a set of safety performance indicators;
(c) Participating in evaluations of the core management and fuel handling process;
(d) Providing feedback derived from performance indicators for operations.

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

2.10. The competence requirements for staff performing the work should be specified and it should be ensured that the personnel deployed are competent to perform their assigned work.

2.11. Personnel whose roles are not dedicated to the research reactor facility and personnel of external suppliers who perform core management or fuel handling activities should be appropriately trained and qualified for the work they are expected to perform. Experienced and qualified personnel may be allowed to bypass training after obtaining an appropriate proof of their proficiency. However, they should in any case be instructed on the work to be done at the reactor and they should be aware of the structure of the reactor core. External personnel would perform activities under the same controls and to the same standards as reactor personnel. Supervisors should review the work of external personnel during preparation for the work and during testing and acceptance testing.

2.12. The hardware and software based process equipment that is necessary for work to be carried out in a safe manner and for meeting requirements should be identified, provided and maintained. Equipment and items used for core management and fuel handling[5] should be identified and controlled to ensure their proper use. Equipment used for monitoring, data collection and inspections and tests should be qualified for the operating environmental conditions and should be calibrated as necessary.

PROCESS IMPLEMENTATION

2.13. Core design and experiment design should be carried out in accordance with established engineering codes and standards.

2.14. The core management and fuel handling activities should be performed and recorded in accordance with approved procedures and instructions.

2.15. 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.

2.16. Inspection, testing, verification and validation activities should be completed before the implementation or operational use of a new core design or experiment design or a new handling technique.

2.17. Valid monitoring and measurement should be established to provide evidence of compliance with requirements and satisfactory in-service inspection.

[5] Fuel handling is discussed in Sections 4–6 of this Safety Guide.

2.18. Suppliers should be evaluated and selected on the basis of specified criteria.

MEASUREMENT, ASSESSMENT AND IMPROVEMENT

2.19. 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 requirements of the experimental programme.

2.20. An organizational unit should be established with the responsibility to conduct independent assessments of the core management and fuel handling programme. This unit is usually the safety committee as described in para. 7.25 of Ref. [1].

2.21. The operating organization should evaluate the results of the independent assessments and should take necessary actions to implement recommendations and suggestions for improvement.

3. CORE MANAGEMENT

GENERAL

3.1. The primary objective of core management is to ensure the safe, reliable and optimum use of the nuclear fuel in the reactor, while remaining within the limits imposed by the design of the fuel assembly and the design of the reactor, on the basis of the safety analysis contained in the SAR and the OLCs derived from the safety analysis. The secondary objective is to meet the requirements of the utilization programme (e.g. the need for neutron flux for experiments) while keeping within the OLCs.

3.2. While the details of core management will depend on the reactor type 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 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 reactor utilization and optimum fuel utilization while remaining within the OLCs;
(c) To ensure that only fuel assemblies and experimental devices of approved design are used.

3.3. The specific safety requirement relating to core management (see para. 7.65 of Ref. [1]) that is addressed in this Safety Guide covers the following:

(a) Validated methods and codes should be used to determine appropriate positions in the core for locating the fuel, reflector, safety devices (control rods[6], valves for dumping the moderator and/or reflector, burnable absorbers, etc.), experimental devices, irradiation facilities and moderators;
(b) The integrity of the fuel assembly should be ensured at all times during the utilization of the reactor core by maintaining relevant core configuration parameters in accordance with the design intent and assumptions as specified in the OLCs for the reactor;
(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 reactor; the effects and safety implications of the irradiation of core material, core components and experimental and irradiation facilities should be assessed;
(d) The integrity of the cladding of the fuel assembly should be continuously monitored (not necessarily monitored 'online' in the reactor but commonly monitored indirectly by monitoring the fission product activity in the primary coolant and off-gas systems), and in the event of detection

[6] 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 the research reactor's reactivity control devices.

of fuel failure an investigation should be initiated to identify the failed fuel assembly and to unload it from the core if necessary;[7]

(e) Fuel procurement should be based on specifications in accordance with the design intent and the requirements of the OLCs;

(f) Approved procedures should be followed for loading and unloading fuel assemblies and other core components;

(g) Baseline information on all the parameters relating to the fuel and core configuration should be maintained and updated.

CORE CALCULATIONS

Analyses of core conditions and characteristics

3.4. A comprehensive safety analysis of the reactor, including core design analysis, should be performed and documented in the SAR (safety analysis is discussed in paras A11 and A16 of Ref. [10]). The OLCs are based on this analysis. 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 changes in core configuration, differences in the types of fuel assembly in use, differences between fuel assemblies because of the burnup history, the presence of other core components or other conditions deviate from those considered in the safety analysis, a more comprehensive analysis should be performed to ensure that the reactor continues to be operated within the OLCs.

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

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

[7] 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.

(a) Variations in reactivity with fuel burnup and actions needed to maintain core reactivity (e.g. by changes in control rod positions, the addition of fuel assemblies and changes in core reflection);
(b) Location and reactivity worth of control rods for all core configurations, 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, power, pressure and void over the normal operating range and for anticipated operational occurrences;
(e) Neutron flux and power distribution in the core components and the fuel, and the effect on these of control rod movement;
(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.

3.7. Due consideration should be given to the effect on the reactor's performance of experimental and irradiation facilities, in or adjacent to the core, that were not considered in the original design. The effect on the reactor of a failure in these facilities should be subjected to safety analysis. The effects of changes in the reactor on the experiment or the irradiation programme should also be considered. A comprehensive discussion of safety analysis for experimental devices is presented in Ref. [6].

3.8. Core reactivity changes and the associated effects during the reactor's 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 control at all times to ensure that the 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.

3.9. 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 may not constitute a source of sufficient strength).

3.10. If there are significant discrepancies (i.e. discrepancies that are greater than the variation that can be attributed to uncertainties in the calculations and the measurements) between the predictions made on the basis of core calculations and the measurements of core characteristics, the 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 based on measurements of key core parameters (e.g. 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

3.11. The operating organization should ensure that the management system discussed in Section 2 includes computational methods and tools used for core management.

3.12. The management system should require 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 computational results (ideally, made by a number of different people using a variety of tools and methods) should be mandatory for significant core management calculations. Special emphasis should be placed on the qualification of methods used to deal with items such as extended burnup, new materials, design modifications, new experimental devices and power increases.

3.13. 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 verified and functionally tested before implementation (e.g. by means of the comparison of predicted results with benchmark codes) and should be approved by the competent body. Physical and/or administrative controls should be established to ensure the integrity and reliability of the associated computer programs and databases.

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

CORE OPERATION

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

(a) It should be ensured that all pre-startup procedural requirements are met and functional tests are completed and that all required documents and/or procedures are updated prior to the startup of the reactor;
(b) The conformance of core parameters with the design intent and assumptions as specified in the OLCs should be ensured 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 reactor startup and as appropriate during subsequent startups;
(c) Surveillance programmes should be established and implemented for all in-core fuel assemblies and for the functions of experiment management and reactivity management.

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

(a) Conformance of fresh fuel to design specifications;
(b) Fuel loading pattern;
(c) Reactivity shutdown margin;
(d) Maximum allowed excess of reactivity;
(e) Rates of addition and removal of reactivity;
(f) Coefficients of reactivity and reactivity worth of experimental devices and the materials being irradiated;
(g) Conformance of control rod characteristics, including speed of insertion and withdrawal, with design specifications;

(h) Characteristics of the control systems and protection systems;
(i) Neutron flux distribution, including perturbations by experiments and by materials being irradiated;
(j) Heat transfer, coolant flow and thermal margins in 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 and fission density limitations;
(n) Fission product activity in the primary coolant and off-gas system;
(o) Reactivity effects of failures in experimental devices.

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

(a) Identification of the instruments as well as the calibration and assessment methods to be used by the operator, so that relevant reactor parameters can be monitored within the 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 fuel or the core, with account taken of changes in core conditions due to fuel burnup 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 flux tilts;
(h) Actions to be taken when the limits are reached;
(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

3.18. A core monitoring programme should be established: to ensure that core parameters are monitored, trended and evaluated to determine that they are acceptable and that the actual core performance is consistent with core design requirements and in compliance with the OLCs; to ensure that values of key operating parameters are recorded and retained in a logical and consistent manner; and to detect abnormal behaviour. The core monitoring programme may be based on parameters that are directly measurable and on values of non-measurable parameters derived by analysis from the values of measurable parameters. When experimental or irradiation facilities are located in or adjacent to the core, the status of these facilities, 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.

3.19. Core conditions should be monitored and compared with predictions to determine whether they are in accordance with the design intent and assumptions as specified in the OLCs (see Ref. [9]). If core conditions do not conform, appropriate action should be taken to maintain the reactor in a safe condition. The results of core monitoring and testing should also be used for review and updating of the refuelling programme and optimization of core performance. Parameters to be monitored (either continuously or at appropriate intervals), trended and evaluated should include, but are not limited to, 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/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:
    (i) Thermal power output from the core;
    (ii) Temperatures of fuel and core components (where not measured);
    (iii) Local 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.

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

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

3.21. The redundant and independent instrumentation for monitoring the relevant parameters should normally be arranged so as:

(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 the operators;
(d) To provide the highest sensitivity to changes in global reactivity and to minimize the impact of localized changes of neutron flux.

3.22. Parameters such as coolant temperatures, coolant flow rates and, when appropriate, coolant pressures should be measured and displayed appropriately to the operator. Where applicable, changes in the core due to refuelling and fuel burnup may require 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 or the initiation of safety actions to maintain the appropriate safety margins.

3.23. 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 the neutron flux and temperatures, pressures and flow rates. The derived values are used as a basic input for establishing OLCs, but values of parameters specified for use by the reactor operator should be given in terms of those values available in the control room from instrument indications or the display of derived values.

3.24. 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 internal temperatures of 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 and experimental and irradiation facilities should be assessed. These assessments and correlations should be recorded in the form of a written document and they should form the basis for ensuring conformance with OLCs and for appropriate corrective action to be taken, if necessary.

3.25. The values of parameters such as those relating to chemical control and purity control are 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, the operating personnel should be provided with instructions concerning the actions to be taken if these parameters tend to approach pre-established limits.

ENSURING FUEL INTEGRITY

3.26. The operating organization should ensure that fuel assemblies are adequately designed and have been manufactured in accordance with design specifications.

3.27. 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.

3.28. Fuel surveillance should be required by the OLCs, as discussed in Ref. [9], for the early detection of any deterioration that could result in an unsafe condition in the reactor core, and should be implemented through a programme of surveillance and in-service inspection as discussed in Ref. [11]. 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 (operability, actuation times and reactivity change rates);
(b) Core cooling systems, including the cooling of core components (flow rate, pressure, temperature, activity and chemistry of the coolant);
(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.

3.29. The reactor fuel cladding should be continuously monitored to confirm its integrity. In an open or pool type reactor (without a forced circulation system) this is best done 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 is detected by monitoring for fission products in the coolant or in off-gas from the coolant. In some cases, a delayed neutron detector located in the coolant flow is used. Appropriate methods should be established to identify any anomalous changes in airborne activity or coolant activity and to perform data analysis to determine:

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

3.30. 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 'tramp' fissionable material (i.e. fissionable material remaining on the outside surface of the cladding from the manufacturing process) and results in a necessarily small, often even undetectable activity.

3.31. One indication of fuel assembly failure is an increase in fission product activity above the normal value. 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. Investigations of particular fission product isotopes may be necessary to characterize failures.

3.32. 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 reactor may be performed to identify the failed assembly and the cause of the failure should then be investigated. In special cases this may involve hot cell examination.

3.33. 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.

NEW FUEL PROCUREMENT AND DESIGN MODIFICATIONS

3.34. 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. The procedures should include requirements that cover:

(a) Verification that current and approved specifications and drawings are being utilized;
(b) Verification that purchase orders specify 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.

Additional guidance concerning the procurement of plate type fuel assemblies is provided in Refs [5, 12]. Information on the procurement process for other core components is provided in Ref. [6].

3.35. If a fuel assembly of a new or modified design (e.g. an assembly containing LEU instead of HEU) is to be introduced into the core, the operating organization should be responsible for ensuring that a safety analysis based on the guidance provided in Ref. [10] has been performed. Prior to operating a core with fuels of more than one type, 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 SAR. The details of the new fuel assembly should be reflected in the OLCs and in other safety related documentation.

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

3.37. The operating organization should be 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 Vol. 4 of Ref. [5]. Appropriate licensing documentation should be prepared for new or modified reloaded fuel. This documentation should include, but is not limited to, the following:

(a) Information on fuel assembly design 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) Safety analysis, including analysis of transients.

3.38. 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:

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

3.39. 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 or not 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

3.40. Fuel handling and storage facilities should be provided in accordance with the requirements established in paras 6.149–6.154 of Ref. [1].

3.41. All fuel assembly movements and core alterations should be strictly controlled through the use of approved operating procedures. Throughout such changes, core integrity and reactivity should be monitored to prevent damage to core components and an inadvertent criticality. Intermediate fuel assembly patterns should be no more reactive than the most reactive configuration considered and approved in the OLCs and verified during 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 actual fuel assembly movements if necessary.

3.42. The refuelling programme should include details of the core configuration and a schedule of movements of core components and experiments into and out of the reactor.

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

(a) Maintaining neutron flux distribution and other core parameters (such as burnup and excess reactivity) within applicable OLCs;
(b) Meeting the requirements with regard to the shutdown margin.

3.44. Aspects that should be considered in the establishment and execution of a refuelling programme should 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 flux distributions, flow patterns and absorber configurations;
(c) Hold points defined in the refuelling programme and in the power ascension following refuelling, at which time 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 practicable to execute, and also to familiarize personnel with the tasks that 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 particular 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 (such as changes in reactivity and local temperature);
(h) Positioning of unirradiated and irradiated fuel assemblies in the core, with account taken of reactivity requirements, 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) Depletion of the neutron absorber in control rods and of burnable absorbers;
(k) 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.

3.45. 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 should be confirmed frequently by means of appropriate testing.

3.46. Checks, including independent verification, should be performed after a fuel reload to provide assurance that the 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 worths throughout their operating range. Tests should include, but should not be limited to, the following, as appropriate:

(a) Withdrawal and insertion of each control rod to check for operability;
(b) Safety system settings and measurements of control rod drop times;
(c) Measurement of the reactivity worth of control rods, experiments and irradiations;
(d) Demonstration that if the control rod with the highest reactivity worth is in the fully withdrawn position and movable experiments and irradiations are in their most reactive conditions, the core meets the specification 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 flux mapping using either temporary or permanently installed in-core detectors;
(g) Comparison of measured and calculated flux distributions and power distributions.

4. HANDLING AND STORAGE OF FRESH FUEL

FRESH FUEL MANAGEMENT

4.1. The safety goals of a fresh fuel handling programme are to prevent inadvertent criticality and to prevent physical damage to the nuclear fuel when it is being transported, stored or manipulated. Fuel assemblies should be protected against damage, in particular damage that could affect the behaviour of the fuel in the core, for example by causing restriction of the coolant flow.

4.2. The principal elements of a fresh fuel handling programme should include receipt, transfer, inspection and storage, in accordance with administratively controlled procedures and engineering practices designed:

(a) To delineate physical boundaries within which new fuel assemblies, which are subject to processes for material control and constraints on the criticality configuration, are to be stored;

(b) To meet administrative requirements and to provide technical instructions for inspections of fresh fuel assemblies, including contingency actions to be taken with regard to damaged fuel.

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

4.4. Handling of fresh fuel assemblies manually, or by means of automated facilities, should be carried out only with equipment specifically designed for that purpose, to reduce the possibility of damaging fuel assemblies during handling. Personnel engaged in fuel handling should be formally trained and qualified and should work under the supervision of an authorized person. All activities relating to handling of fresh fuel should be performed in accordance with approved procedures.

4.5. Fuel assemblies suspected to have been damaged during handling or storage should be inspected, quarantined and, if necessary, treated in accordance with established procedures relating to damaged fuel assemblies (see para. 4.16 of this Safety Guide).

4.6. When fuel is handled manually, suitable protective clothing should be worn 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 transported between buildings on the site, suitable and appropriately labelled containers and packaging should be used to prevent damage to or contamination of the fuel. Routes for all fuel assembly movements should be kept as short and simple as possible. Vehicular traffic during the transportation of fuel assemblies 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 should be controlled at all times 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 fuel. A storage area should not be part of an access route to other operating areas.

4.10. To prevent damage to stored fuel by the accidental dropping of heavy loads, such loads should not be moved in the space above stored fuel (in racks, storage canisters or lifting devices). Any exemptions 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. 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 (as in the case of fuel containing reprocessed materials) should be handled in accordance with approved procedures specifically developed to reduce the exposures of personnel.

RECEIPT OF FRESH FUEL

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 on the site and that access to the fuel assembly 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. The reception and unpacking of fresh fuel assemblies should take place in an area that is designed for fuel handling. An inspection programme for fresh fuel assemblies should be put in place to check the external appearance of the fuel assembly and to check for any damage sustained during transport. Inspection of the fuel assembly should include the comparison of specified parameters (such as dimensions) that may have been affected by transport and handling since the supplier's final inspection with those in the history dockets provided by the supplier. The fuel assembly identification number should be verified and related documentation should be checked to confirm that the fuel received corresponds to what was ordered and conforms to requirements.

4.16. The procedures for the identification of damaged fuel assemblies should be reviewed if fuel of a new design is procured. Acceptance criteria for assessing damaged fuel should be available. 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 damage should be investigated and corrective measures should be taken to prevent their recurrence.

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

4.18. Inspections should neither damage the fuel assembly nor introduce any foreign material into it. Inspectors should identify any foreign material already present in the fuel assembly and should arrange for its removal following 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 carried out 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

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 to the site. If fuel of a new design is to be delivered, if fuel enrichment is changed or if reracking of a storage area is necessary, the validity of the safety analysis pertaining to criticality in the SAR should be reassessed.

4.21. An adequate number of specified storage positions should be available to ensure the integrity of fuel assemblies and to prevent damage to them.

4.22. Physical 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.

4.23. 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.

4.24. For the storage systems that use fixed solid neutron absorbers, a surveillance programme should be put in place to ensure that the absorbers are installed and to verify that they retain their effectiveness.

4.25. 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.

4.26. 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 may potentially give rise to criticality.

4.27. Fire risks should be minimized by preventing the accumulation of combustible material in the storage area. Instructions for firefighters and instructions for the use of firefighting equipment suitable for use on fires involving fuel assemblies should be readily available. Personnel should be trained in fire response so as to be in a state of preparedness. Approved procedures should be put in place to control the introduction of moderating material or oxidizers (e.g. water), or the introduction of diluting neutron absorbing media (e.g. borated water) into the fresh fuel storage area, so that subcriticality will always be maintained, even if fire extinguishing materials are used. Relevant information on fire safety is provided in Ref. [13].

4.28. 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 where only fuel handling activities should take place.

4.29. Before the first fuel assembly is delivered to the fuel storage area, the relevant parts of the radiation protection programme should be in effect.

5. THE REFUELLING PROGRAMME

PREPARATION

5.1. The refuelling process described in paras 3.40–3.46 of this Safety Guide will form the basis for a programme which should be implemented by means of approved procedures that specify in detail the sequence of the operations to be carried out. 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 fuel assembly to be shuffled or unloaded; its original position in the core; its new location either in the core or in the storage areas; the sequence for unloading and loading fuel assemblies and other components such as control rods; and the checks to be performed at each stage. 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.

5.2. The steps necessary to prepare fresh fuel assemblies for use in the reactor should be specified in written procedures. Only approved fuel (see paras 3.26–3.27 of this Safety Guide) should be loaded into the reactor core. Independent checks should be carried out to confirm that the core has been assembled correctly. In all procedures for fuel handling and maintenance, it should be ensured as far as possible that no foreign materials are introduced into the reactor.

5.3. Any equipment required for core monitoring during the refuelling process should be tested during the preparation process to ensure that it is operating properly. Reliable means of two way communication between the fuel handling staff and the control room staff should be available at all times.

LOADING FUEL AND CORE COMPONENTS INTO THE REACTOR

5.4. When a fuel assembly is moved from storage, it should be identified and checked against the approved programme. Arrangements should be made to ensure as far as possible (for example, 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 programme.

5.5. While handling procedures may be simpler when a reactor core is being loaded for the first time, since the fuel assemblies and core components have not yet been irradiated, refuelling procedures and management system requirements should still be followed. All fuel handling tools and equipment, whether for manual or automated handling, should undergo commissioning tests and pre-use checkout prior to use with fuel assemblies. Reference [14] provides further guidance on these aspects. Procedures should be verified and fuel handlers should be trained using 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 reactor operation is commenced. Dummy or test fuel assemblies should be clearly distinguishable, even when in the core.

5.6. Core components (instrumentation, coolant flow orifice plate, plug, control rods, neutron absorber, and fixtures for experimental or irradiation facilities) 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 requirements. Safety aspects relating to neutron sources and core components that have not been taken into account in the fuel loading plan should be considered before these assemblies and components can be loaded into the reactor core. Guidance for the first core loading is provided in Ref. [14].

5.7. Procedures should be prepared to control the movement of any core component into or out of the core. Checks should be incorporated, where possible, to ensure the satisfactory insertion of the fuel.

5.8. When a significant quantity of fuel is being loaded or a core component (control rod, neutron absorber, experimental or irradiation devices, etc.) is being moved into a shutdown reactor, the 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

5.9. Fuel assemblies and core components should be unloaded in accordance with an approved programme. Adequate cooling of the fuel assemblies and core components should be ensured in all steps of the programme.

5.10. The identification of the fuel assemblies or core components should be checked against the programme each time that one is moved to a new location. An error found in either the original loading or in the reloading should be documented and reviewed by the appropriate personnel to ensure that a correction is made.

5.11. For purposes of radiation protection, precautions to be taken when handling unloaded fuel, core components and materials and in any disassembly operations should be specified in the 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 the risk of undue radiation exposure.

5.12. 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 require the examination of adjacent components. Any repairs should be made on the basis of proven techniques and carried out in accordance with approved procedures and with reference to the manufacturer of the fuel assembly.

5.13. A fuel assembly that is known to have failed should be quarantined to prevent its subsequent inadvertent use and should be suitably treated to reduce contamination of the storage facility and to permit compliance with the applicable requirements for transport 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.

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

HANDLING FUEL AND CORE COMPONENTS

5.15. Procedures for handling fuel and core components should include the necessary precautions to ensure safety. Aspects to be considered should 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:

(a) Criticality arising, for example, 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 personnel due to radioactivity from components or material released during handling.

5.16. Recommendations and guidance on additional considerations that apply to the initial core loading, initial criticality and commissioning of a research reactor are provided in Ref. [14].

5.17. Considerations for the handling of reactor fuel and core components vary substantially between various reactor types, fuel assembly designs, power densities and operating histories. Typical considerations may include:

(a) Establishment of controls and supervision for radiation protection purposes;
(b) Availability and operability of appropriate tools and equipment, including, if necessary, devices to aid visual access 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 rendering them inoperable;
(h) Specified minimum time between shutdown and commencing the movement of fuel assemblies and core components;
(i) Specification of required safety instrumentation in operation and of frequency of checking;
(j) Availability of appropriate cooling and emergency cooling capabilities;
(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 and core components have been correctly loaded and properly positioned in or fixed into the core grid;
(p) Establishment of contingency procedures and emergency procedures for fuel handling incidents.

6. HANDLING AND STORAGE OF IRRADIATED FUEL

GENERAL OBJECTIVES

6.1. Fuel assemblies that have been utilized in the reactor will be highly radioactive and will contain radioactive fission products that are retained in the fuel assembly. The safety objectives associated with the handling and storage of irradiated fuel assemblies are:

(a) To ensure subcriticality at all times;
(b) To prevent damage to fuel assemblies;
(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.

HANDLING OF IRRADIATED FUEL

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

6.3. All movement, handling, storage and inspection of irradiated fuel assemblies should be performed in accordance with approved procedures. Key operations should be verified and signed off by authorized personnel.

Equipment used for the movement of irradiated fuel assemblies should be qualified and tested before use. A system should be put in place to account for the nuclide inventory and the decay heat of the irradiated fuel, if relevant.

6.4. The spread of contamination should be controlled to ensure a safe operational environment and to prevent unacceptable releases of radioactive material. For this purpose, dedicated equipment and procedures are necessary to cope with damaged or leaking fuel. Sealable containers of approved design for leaking fuel assemblies should be readily available.

6.5. Shielding, as necessary, should be provided around all areas in which irradiated fuel may be placed. This is necessary to protect personnel and to ensure that their exposure to direct radiation from fission products and activated materials is kept as low as reasonably achievable (see Ref. [15]).

6.6. Handling and storage areas for irradiated fuel assemblies or fuel handling tools that are required to remove fuel assemblies should be secured against unauthorized access or unauthorized removal of fuel. Core components intended to be handled or stored in areas for irradiated fuel assemblies should be managed in a specified and safe manner on the basis of approved procedures.

6.7. Appropriate procedures should be established to manage anticipated operational occurrences and design basis accidents 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 or failures of safety related systems) and those external to the facility (e.g. seismic events, extreme meteorological conditions, loss of off-site electrical power or security related incidents).

STORAGE OF IRRADIATED FUEL

6.8. Adequate storage sites should be available for the storage of irradiated fuel. 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 fuel assemblies in the storage facility during its lifetime should be considered.

6.9. In particular, conformance with approved configurations and, if necessary, requirements for neutron absorbers in the storage facility should be ensured. Specified neutron absorbers may be fixed absorbers (i.e. boral plates) or, for pool storage, dissolved neutron absorbers in the pool water. A surveillance programme should be put in place to ensure the integrity of any neutron absorbers used for fuel storage units. Suitable administrative procedures for ensuring subcriticality should be implemented.

6.10. If residual heat from irradiated fuel is significant, reliable heat removal should be ensured to prevent unacceptable degradation of the fuel assemblies that could result in a release of radioactive material. It should be ensured that the bulk temperature of the pool water as well as the variations in and the rates of change of temperature are maintained within acceptable limits and that pool makeup 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. For dry storage facilities, it should be ensured that there are no impairments (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.

6.11. For storage under water, the chemical and physical characteristics of the pool water should be maintained in accordance with OLCs so as:

(a) To avoid the corrosion of fuel, core components and structures in the pool by maintaining suitable pH values and other chemical 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 (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.

6.12. To avoid damage to 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. 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.

6.13. Storage areas for irradiated fuel should be subject to access control for purposes of radiation protection and security. Access should be limited to authorized personnel with appropriate training and all operations should be performed in accordance with approved written procedures. Provision should be made for the continuous monitoring of access.

6.14. Examples of the precautions that should be taken with pool storage to limit radiation exposures include the following:

(a) The pool water level 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 limited 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;
(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 (work permits) should be put in place;
(g) Dose history records and medical records of personnel should be maintained.

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

6.16. For some reactors, it may be important to safety to retain sufficient storage capacity to accommodate the fuel inventory of the reactor and the control rods at any given time.

6.17. A policy should be adopted for the exclusion of foreign materials from irradiated fuel assemblies in storage. Approved procedures should be in place to control the use of certain materials such as loose parts or transparent materials that cannot be seen under water.

6.18. Plans should be prepared for dealing with damaged or leaking fuel assemblies and appropriate storage arrangements should be made for these, such as:

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

INSPECTION OF IRRADIATED FUEL

6.19. 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. 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 assembly. Examples of possible attributes of such a programme are:

(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 such fuel in hot cells to study structural behaviour;
(c) Established arrangements for the feedback and exchange of information with the supplier of the assembly.

6.20. 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

7.1. Aspects to be considered in the handling and storage of unirradiated core components should include preventing damage, ensuring cleanness and preventing radioactive contamination. In this regard, care should be exercised in the design of handling tools for core components. For the purpose of this Safety Guide, the term ‘core components’ includes such items as 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, particularly irradiated core components, and other items such as storage containers or shipping casks 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 remain 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, out of core storage position and other pertinent information so that an irradiation history of the component is available.

7.5. Core components may become highly radioactive during operation of the 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 component that is to be reused or that needs to be retrievable for other reasons should be accessible;
(f) Where inspection of irradiated components is necessary, interlocks should be provided and other appropriate measures should be taken to protect operators against exposure;

(g) Means to transfer irradiated components into suitable shipping containers should be provided where necessary.

7.6. Without impairing the required storage capacity for core components, an appropriate space should be provided for the storage and use of handling tools, other tools and equipment necessary for the disassembly and surveillance of core components.

7.7. Adequate arrangements should be made for the clear identification of all neutron sources available at the reactor site and administrative measures for their control should be put in place. They should be shielded and should be treated appropriately. Contamination checks should be performed following the receipt of transport containers containing neutron sources. The transport containers for neutron sources should be clearly marked in accordance with the regulatory requirements.

7.8. Where appropriate, programmes 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. These programmes should include examination of components to be returned to the core for further service and examination of discharged components to detect significant degradation during service. Maintenance programmes should include procedures to prevent the introduction of foreign materials into the reactor.

8. PREPARATION OF FUEL FOR DISPATCH

8.1. The operating organization should ensure that an appropriate management system is in place for use during the preparation of fuel assemblies for dispatch from the reactor facility.

8.2. Fuel should be removed from the reactor facility 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.

8.3. Preparation of fuel for dispatch may include cutting off non-fuelled end pieces so that the cropped fuel assembly will fit into the shipping cask or reducing the amount of non-fuelled material sent for further disposition. Such work should be performed following approved procedures that include appropriate training and supervision of personnel as well as radiation protection oversight and monitoring.

8.4. The shipping cask should be selected according to the fuel to be loaded. The cask should be approved by the competent authority for use for such fuel, with consideration of the fuel type, number of elements and content of fissile material to ensure criticality safety, and including burnup, irradiation history and cooling time to ensure that the radiation levels and decay heat levels remain within the specified limits for the cask. If the cask requires special 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 container. The cask should also be labelled in accordance with the applicable transport regulations and should be clearly marked with radiation symbols and other necessary identification (see Ref. [16]).

8.5. Procedures should be established for the preparation of the transport cask for transport off the site. The procedures should be followed to ensure, in particular, that the transport cask is properly loaded, closed and sealed and has adequate cooling capability, and that radiation levels and contamination levels meet the applicable transport requirements. Other approved procedures for the preparation of the cask may be also required (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 is available and has been functionally tested and is of proven reliability. Procedures should be established with 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. Procedures should include the generation of the proper records and shipping documents.

8.6. The transport vehicle together with the transport cask should be checked for compliance with transport requirements, including those for cask tie-down, vehicle placarding and external contamination and radiation levels, before its dispatch from the site.

8.7. A cask 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 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 cask is opened, radiation monitors with alarms should be checked to be operative, and suitable measures should be taken (such as opening the casks under water) to prevent accidental exposure of personnel if radioactive material of significant activity has remained in the cask.

8.9. Requirements for the safe transport of radioactive material are established in the IAEA Regulations for the Safe Transport of Radioactive Material [16].

9. ADMINISTRATIVE AND ORGANIZATIONAL ASPECTS

9.1. The operating organization is responsible for the overall safety of the research reactor facility while the reactor manager has direct responsibility for its safe operation [1, 3]. While in most research reactor organizations 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 or predictions of performance). In all cases, the operational aspects of core management and the fuel handling activities at the reactor site should be the direct responsibility of the reactor manager.

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

9.3. All activities for core management and fuel handling should be carried out in accordance with approved procedures and documented in records as specified in procedures. The procedures and records should be in accordance with the management system as discussed in Section 2.

9.4. The operating organization should identify the key competences necessary for the tasks, such as competence in criticality assessment and transient analysis and expertise in techniques for carrying out core calculations. For low power research reactors, envelopes and margins established by the reactor supplier in the initial safety analysis or design report may be sufficient guidance for the lifetime of the reactor provided that 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 should ensure that the necessary competences are established and maintained to meet the required level of safety. If tasks are to be contracted out, the operating organization, including the reactor manager, should have sufficient knowledge of the work done to judge its technical validity and should know where to seek advice and assistance if necessary.

9.5. The operating organization should ensure that approved procedures are put in place to control the various safety related aspects of core management and fuel handling, including:

(a) Receipt, storage, handling, inspection and disposition of fuel assemblies and core components;
(b) Recording of the locations, associated dose rates, physical condition and disposition of fuel assemblies and core components;
(c) Core surveillance to meet the requirements for core management;
(d) Tests to obtain values for core parameters such as those described in para. 3.19 of this Safety Guide (where appropriate);
(e) Actions to be taken by reactor operators whenever core parameters are outside the specified limits and conditions 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 Ref. [6]);
(g) Reporting and investigation of unusual occurrences, including root cause analysis.

9.6. Lessons learned from experience can be applied to enhance safe operation. Safety related information obtained from operating experience relating to fuel should be recorded and should be exchanged with the supplier, with other research reactor operators and with the regulatory body.

10. DOCUMENTATION

10.1. For the safe operation of a research reactor, the operating organization should have adequate information on the fuel, 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.

10.2. This baseline information should be augmented during subsequent operation by means of a comprehensive records system covering core management and handling activities for 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 and of activities relating to safety throughout the operating lifetime of the reactor. Requirements for record keeping are established in Ref. [7].

10.3. Typical records important to core management and the handling of fuel and core components should include, but are not limited to, 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 (typically, hourly logs of parameters such as temperature and flow rate);
(e) Power levels and time at power;
(f) Reactivity balance and critical configuration when starting up;
(g) In-core 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 and 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.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. NS-R-4, IAEA, Vienna (2005).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors, IAEA Safety Standards Series No. NS-G-4.5, IAEA, Vienna (2008).
[3] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Core Management and Fuel Handling for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.5, IAEA, Vienna (2002).
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Research Reactor Core Conversion Guidebook, Vols 1–5, IAEA-TECDOC-643/1–5, IAEA, Vienna (1992).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety in the Utilization and Modification of Research Reactors, Safety Series No. 35-G2, IAEA, Vienna (1994).
[7] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Research Reactors, IAEA Safety Standards Series No. NS-G-4.4, IAEA, Vienna (2008).
[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report, Safety Series No. 35-G1, IAEA, Vienna (1994).
[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Periodic Testing and Inspection of Research Reactors, IAEA Safety Standards Series No. NS-G-4.2, IAEA, Vienna (2006).
[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Standardization of Specifications and Inspection Procedures for LEU Plate-type Research Reactor Fuels, IAEA-TECDOC-467, IAEA, Vienna (1988).
[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Fire Safety in the Operation of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.1, IAEA, Vienna (2000).
[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning of Research Reactors, IAEA Safety Standards Series No. NS-G-4.1, IAEA, Vienna (2006).
[15] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).
[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material (2005 Edition), IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2005).

Annex

REASONS FOR CORE MANAGEMENT FOR RESEARCH REACTORS

A–1. The core of a research reactor will contain fuel assemblies, moderator, reflectors, reactivity control devices, neutron absorbers and experimental apparatus. 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 fulfilling the requirements of the OLCs.

A–2. Core management must accommodate the changes to the core brought about by modifications including:

(a) Fuel 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 by the addition of a fuel assembly);
(c) Reflector modifications to compensate for burnup (e.g. the insertion of a more efficient reflector in place of the existing reflector);
(d) Replacement of reactivity control devices;
(e) Removal of experimental apparatus following completion of an experiment;
(f) Insertion of new experimental apparatus (e.g. a 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 reactors with a fixed core configuration for fuel, reflectors, reactivity control devices and experimental facilities, core management may consist exclusively of compensation for burnup or lifetime radiation fluence limitations.

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