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STANDARDS
SERIES

Core Management and Fuel Handling for Nuclear Power Plants

SAFETY GUIDE

No. NS-G-2.5

INTERNATIONAL
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CORE MANAGEMENT AND FUEL HANDLING FOR NUCLEAR POWER PLANTS

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

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SAFETY GUIDE

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FOREWORD

By Yukiya Amano
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State’s activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission for Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA’s safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the

IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form ‘shall’ in making statements about requirements, responsibilities and obligations. Use of the form ‘should’ denotes recommendations of a desired option.

The English version of the text is the authoritative version.

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1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide supplements and elaborates upon the safety requirements in Sections 6 and 7~~.18-7.29~~ (Requirement 25, 30) for core management and fuel handling that are established~~presented~~ in Ref. ~~Safety Requirements publication on the operation~~ ~~and commissioning~~ ~~of nuclear power plants~~ Safety of Nuclear Power Plants: Commissioning and Operation, Specific Safety Requirements, IAEA Safety Standards Series No. SSR-2/2 (Rev. 1) [1]. This publication is a revision of the IAEA Safety Guide on Core Management and Fuel Handling for Nuclear Power Plants, issued in 2002 as IAEA Safety Standards Series No. NS-G-2.5. It is also related to the Safety Guide ~~on the Operating Organization for Nuclear Power Plants~~ Ref. The Operating Organization for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.4 [2], which identifies fuel management as one of the various functions to be performed by the operating organization.

OBJECTIVE

1.2. The purpose of this Safety Guide is to provide recommendations for core management and fuel handling at nuclear power plants on the basis of current international good practice. The present Safety Guide addresses those aspects of fuel management activities that are necessary in order to allow optimum reactor core operation without compromising the limits imposed by the design safety considerations relating to the nuclear fuel and the plant as a whole, Ref. Safety of Nuclear Power Plants: Design, Specific Safety Requirements, IAEA Safety Standards Series No. SSR-2/1 (Rev. 1) [3]. In this publication, ‘core management’ refers to those activities that are associated with fuel management in the core and reactivity control, and ‘fuel handling’ refers to the receipt of fresh fuel, movement, storage and control of fresh and irradiated fuel as well as handling of fuel casks in the spent fuel pool. ‘Fuel management’ comprises both core management and fuel handling. In addition, the application of the recommendations of this ~~s~~Safety ~~g~~Guide will support the fostering of a strong safety culture.

SCOPE

1.3. This Safety Guide deals with fuel management for all types of land based stationary thermal neutron ~~nuclear~~ power plants. It describes the safety objectives of ~~core~~ ~~fuel~~core management, the tasks that have to be accomplished to meet these objectives and the activities undertaken to perform those tasks.

1.4. It also deals with the receipt of fresh fuel, storage and handling of fuel and other core components[1], the loading and unloading of fuel and core components, and the insertion and removal of other reactor materials.

1.5. In addition, it deals with loading a transport ~~container~~ cask with irradiated fuel and its preparation for transport off the site. Transport requirements and safety precautions for transport beyond the site, off-site storage and ultimate disposal of irradiated fuel and core components are beyond the scope of this publication.

1.6. Aspects of fuel accounting not directly related to nuclear safety are not considered in this publication; thus, safeguards are beyond the scope of this publication.

STRUCTURE

1.7. Section 2 provides guidance on the core management programme. Section 3 identifies the main aspects of handling and storage of fresh fuel. Section 4 gives guidance on the implementation of the refuelling programme. Section 5 explains the different aspects of handling, storage and inspection of irradiated fuel. Section 6 deals with the handling of core components, in particular those that have been irradiated. Section 7 provides general recommendations on the preparatory arrangements in connection with fuel dispatch from the site. Sections 8 and 9 give guidance on administrative and organizational arrangements for fuel management, including general aspects of documentation.

2. CORE MANAGEMENT

OBJECTIVE OF CORE MANAGEMENT

2.1. The objective of core management is to ensure the safe and reliable use of the nuclear fuel in the reactor, with due consideration of the limits imposed by the design of the fuel and of the plant, on the basis of the safety analysis (see Ref. Design of the reactor core for nuclear power plants, IAEA Safety Standards Series No. NS-G-1.12 [5] and Ref. Deterministic safety analysis for nuclear power plants, IAEA Safety Standards Series No. SSG-2 [6]~~footnote 1~~). [PH1]For maximum efficiency, heat flux and coolant temperatures need to be as high as possible, while at the same time the key parameters must be kept within operational limits. Because of this,

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[1] Furthermore, in the text the term ‘other core components’ has been replaced by ‘core components’, it being understood that fuel (fuel assemblies) and other elements of the construction are likewise core components.

high levels of expertise and meticulous control of the associated operations are essential.

2.1A Defence in depth for core management should cover a number of operational levels of defence (thorough planning of core management activities, equipment and procedures, core analysis and monitoring, fuel integrity monitoring, contingency measures, etc.) aimed at ensuring the fuel integrity, preventing accidents and ensuring appropriate protection in the event that prevention fails.

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

- To provide the means to perform core management functions effectively throughout the fuel cycle in order to ensure that core parameters remain within the approved operating limits. Core management functions include: core performance monitoring (including provision of redundancy for key instruments and procedures for dealing with loss of functions); thermal-mechanical evaluation; and making fuel depletion calculations, reactivity calculations, neutronic calculations and thermal-hydraulic state calculations;
- To provide support for core operating strategies in order to obtain maximum operating flexibility and optimum fuel utilization, at the same time remaining within the established safety limits;
- To ensure that only fuel assemblies of approved design are handled.

2.3. The basic core management tasks to be undertaken to ensure the safe use of the fuel in the core should include, but are not limited to, the following:

- Procuring fresh fuel in accordance with safety requirements (see also Appendix III in the Safety Guide Ref. ~~Q6 on Quality Assurance in the Procurement of Items and Services Application of the Management System for facilities and Activities~~ Application of the ~~m~~Management ~~s~~System for Facilities and Activities, ~~Safety Guide,~~ IAEA Safety Standards Series No. GS-G-3.1 [4]);
- Ensuring the integrity of the fuel by maintaining relevant core operating parameters in accordance with approved operational limits and conditions;
- Securing the ability to shut down the reactor from any operational or transient state;
- Unloading fuel when its specified burnup or dwell time limit has been reached, or if operating experience (corrosion, leakage, bowing) necessitates an earlier discharge;
- Avoiding reloading fuel that cannot be left in the core until the end of the fuel cycle;
- Providing safety justification before allowing any fuel assembly to exceed its ~~calculated~~ limiting conditions;

- Detecting failed fuel and unloading it if necessary;
- Updating plant operating strategies on the basis of fuel performance and operational experience gained with the plant and from other plants;
- Assessing the safety implications, including seismic and dynamic responses of any component or material proposed for insertion into the core or the reactor vessel;
- Assessing the effects of irradiation on core components and adjacent reactor internals.

CORE ANALYSIS

Analyses of core conditions and characteristics

2.4.A. Core analysis should be done in accordance with recommendations set out in Ref.[5].

2.4.B. Reactor core analysis should be carried out at appropriate times to ensure throughout the reactor's operating lifetime that the operational strategy and the limitations on operation do not violate the design limits.

2.4.C Reactor core analysis should be performed to cover the entire operating cycle for ~~the following~~ a variety of reactor core conditions, such as[GS2][CR3]:

- Full power, including representative power distributions;
- Load following (as applicable);
- Approach to criticality and power operation;[GS4][CR5]
- Power cycling;-
- Start-up;
- Refuelling;
- Shutdown;
- Anticipated operational occurrences;
- Operation at the thermal-hydraulic stability boundary (for boiling water reactors (BWRs)[GS6][CR7]).

2.4.D. Whenever the management of fuel in the core is changed or any characteristics of the fuel elements (such as the fuel enrichment, fuel element dimensions, fuel element configuration, or the fuel cladding material) are changed, a new core analysis should be performed and documented.

2.4.E. The reactor core analysis should include fuel element performance analysis based on average and local power levels and axial temperature or void distributions to demonstrate that the respective thermal and mechanical fuel design limits are met for all operational states. -For light water reactors (LWRs)[GS8][CR9], the reactor core analysis should include peak channel power and peak linear power rates for normal full power operation and steady state power distributions at each assembly location and axially along the fuel assembly(s). Allowance should be made to account for the effects of changes in the geometry of the assembly on neutronic and thermal-hydraulic performance (e.g., changes in the moderator thickness due to bowing of the assembly). The reactor core analysis should also include the radial power distribution within a fuel assembly and the axial power distortion due to spacers, grids and other components in order to identify hot spots and to evaluate the local power levels.

2.4. In ~~a comprehensive core management programme~~the analysis of core conditions, account should be taken of the fuel types in use. ~~It should be ensured that appropriate numerical methods and techniques are available and will be used to predict reactor behaviour during operation so as to make sure that the reactor will be operated within operational limits and conditions. Computational models, numerical methods and nuclear data should be verified, validated and approved and uncertainties in measurement should be taken into account.~~ Neutronic, thermal-hydraulic and mechanical analyses should be performed for detailed core analysis. ~~Core analysis~~It ~~Calculations~~~~calculations~~should include, but should not be limited to, the following core parameters for both steady state and transient conditions:

- Variations in reactivity with burnup of the fuel and actions needed to maintain core reactivity, for example, by changes in control rod positions, ~~poison~~ neutron absorbers~~worths~~, coolant temperature and void content, or refuelling rate;
- Location and reactivity worth of all control rods or rod groups;
- The rate of change of the concentration of soluble absorber in the moderator and the coolant;
- Reactivity coefficients of temperature (for the fuel; moderator and coolant), power, pressure and void over the operating range and for anticipated transient conditions;
- Neutron flux and distribution of power in the core and within the fuel assemblies and their control by appropriate movement of control rods or zonal absorbers;
- Fuel and moderator temperatures, coolant flow rates, pressure drop, and temperature, density and thermal margins of the coolant;
- Stability of the power distribution;~~.~~
- Validity of the safety analysis is maintained; ~~The performance characteristics of safety system equipment including thechangeover from one mode of operation to another (e.g. from theinjection mode for emergency core cooling to the recirculation mode);~~
- Changes in~~The decay of~~ xenon concentration due to transients~~and other neutron absorbers in the longterm core analysis~~.

2.5. ~~As a consequence of plant operations, burnup and refuelling, the core~~

~~reactivity changes. This necessitates movements or changes in the configuration of the reactivity control devices that affect the power distribution.~~ ~~These C~~C~~c~~hanges in the parameters exemplified above [CR10]and their effects should be predicted for both steady state and transient conditions. The results of such predictions should be compared with measured parameters as far as practicable, and should be used to confirm that there is sufficient capability for control at all times to ensure that the reactor will be shut down safely and will remain shut down following any normal or fault condition, with limited failures taken into account.

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

- Variation in the reactivity worth of control rods due to irradiation effects;
- Effects of irradiation and control rod shadow effects on neutron flux detectors, particularly the variation in sensitivity;
- The adequacy of the neutron source strength and the sensitivity and location of neutron detectors for startup, especially following a long shutdown (the irradiated fuel and photoneutrons may not constitute a source of sufficient strength).

2.7. If there is significant discrepancy between measurements and calculations, the following actions should be taken in the order indicated:

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

Further in~~Detailed~~ ~~[CR11]~~~~in~~formation on the reactor core analysis can be found in ~~the~~ Ref.[5].

Computational methods for core calculations

2.8. The operating organization should ensure that appropriate numerical methods and techniques are available ~~at the plant~~ and can be used to predict reactor behavior during operation so as to make sure that the reactor will be operated within operational limits and conditions. Computational models, numerical methods and nuclear data should be verified, validated, benchmarked, amended and kept up to date, as necessary. The uncertainties in measurement should be taken into account.~~an appropriate quality assurance programme is in place which covers computer applications used for on-line and off-line core calculations, and which provides traceability and reproducibility~~.

2.8.A Where possible[CR12], validation tests should be simulated without having any prior knowledge of the experimental results to preclude any deliberate tuning of code calculations to yield better agreement with experimental results. See Ref. Deterministic Safety Analysis for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-2 [5A].

2.9. ~~The quality assurance programme should be used to ensure that the computational methods and tools used for in-core fuel management are validated, benchmarked, amended and kept up to date, as necessary. Furthermore, ~~I~~i~~ndependent verification of computational results (ideally, using diverse people, tools and methods) should be performed for significant core management calculations. Special emphasis should be placed on the qualification of methods to address items such as extended burnups, new materials, design modifications and power upratings. More guidance on the verification and validation of computer codes used for safety analysis purposes can be found in Ref.[6].

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

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

CORE OPERATION

2.12. To ensure safe operation of the core, an effective core operation programme should be established. Optimization of fuel utilization and flexibility in core operation should not compromise safety. The core operation programme should include, but should not be limited to, the procedures and engineering practices which:

- Ensure 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 reactor startup;
- Ensure that required measurements of criticality and shutdown margin, low power physics tests, core physics measurements and power raising tests are performed during reactor startup;
- Establish and implement a surveillance programme for all required in-core fuel management and reactivity management functions.

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

- Conformance of fresh fuel to design specifications;
- Fuel loading patterns;
- Reactivity shutdown margin;
- Heat transfer, coolant flow, pressure, temperatures, water level (for BWRs) and thermal margins;
- Rates of addition and removal of reactivity;
- Coefficients of reactivity;
- Worth of control rod banks and dissolved boron (for pressurized water reactors (PWRs)[GS13][CR14]);
- Worth of control rod banks and~~or~~ recirculation flow rate (for BWRs);
- Characteristics of the control and protection systems;
- Neutron flux and power distribution;
- Core stability;
- Heat dissipation from the core to the ultimate heat sink in all operational states and in accident conditions;
- Coolant and moderator chemistry and moderator condition;
- Ageing effects resulting from irradiation and thermal stresses;
- Fission product activity in the primary coolant and the off-gas system.

2.14. The operating ~~procedures~~ requirements for reactor startup, power operation, shutdown and refuelling ~~should~~ include precautions and limitations necessary for the maintenance of fuel integrity and compliance with the operational limits and conditions throughout the life of the fuel (see ~~R 7.23 in~~ Ref.[1]). ~~In~~ Following these requirements in core operating procedures, the following should be taken into consideration, as appropriate:

- Identification of the instruments and the calibration and assessment methods to be used by the operator, so that the relevant reactor parameters can be monitored within the range consistent with the design intents and safety analysis;
- Pre-startup checks, including fuel loading pattern, coolant flow and temperature, and pressure circuit integrity;
- Alarm and safety settings to avoid damage to the fuel, the core or the primary circuit, allowing for changes in core conditions due to fuel burnup or refuelling;
- Operating history of each fuel assembly, especially before refuelling;
- Parameters to be recorded for comparison with predictions of core conditions;
- Limits for the chemical parameters of the primary coolant and moderator;
- Limits for the primary coolant flow;
- Limits on the rate of power raising;

- Limits on power densities and flux tilts;
- Actions to be taken when the limits are reached;
- Control rod patterns and sequencing (see paragraph 2.51);
- Actions to be taken in the event of control rod malfunction;
- Criteria for determining fuel failure and the actions to be taken when failure is indicated.

2.14.A With the aim of protecting fuel against pellet–cladding interaction, the vendors' recommendations on the power manoeuvring should be taken into consideration. The appropriate restrictions in the form of prescribed preconditioning rules, limitations of operating time at reduced power (to limit fuel deconditioning[2]), ramp rates and power level holds (to prevent excessive pellet–clad interaction for the load following operation) should be addressed. Special attention should be given at the first start up after handling of the fuel assemblies, where more severe power ramp rates are applied.

2.14.B The core power should be controlled globally and locally in such a way that the peak linear heat rate of each fuel element and minimum critical heat ~~power~~flux ratio are kept within the appropriate limits for the operational ~~and~~ conditions anywhere in the core. Variations in the power distribution caused by local variations in reactivity due to, for example, xenon instability, changes in coolant conditions and changes in the positions and characteristics of flux detectors should be taken into account in the power evolutions.

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

2.14.D Reliable core cooling should be ensured under all conditions (normal and abnormal). Operations personnel must have certainty regarding the status of core cooling.[CR15]

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

REACTIVITY MANAGEMENT PROGRAMME

2.15.A A reactivity management programme should be established and maintained at the plant to ensure the integrity of the barriers that prevent fission product release. The reactivity management programme should include all the activities that ensure

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

that core reactivity and stored nuclear fuel (where the potential for criticality~~ can occur~~ exists) are monitored and controlled consistent with operational limits and conditions. The following aspects should be addressed in the reactivity management programme:

- Nuclear fuel should be operated, handled and stored in a monitored and defined condition within the boundaries of fuel and core operational limits and conditions.
- Control rods should only be manipulated in a deliberate, carefully controlled manner, while the reactor response is monitored closely.
- Reactivity changes and manipulations should be procedurally controlled to ensure deliberate and predictable outcomes.
- Reactivity changes should be closely monitored to verify the expected magnitude, direction and effects.

2.15.B Reactivity monitoring strategies and operating procedures should be developed for reactivity management. Plant personnel should be trained to understand the strategies and be capable of implementing the procedures, ~~Contingency~~Emergency [CR16][CR17]plans should be developed for situations when emergent reactivity management issues occur. The importance of maintaining margins to core operational limits should be highlighted as part of the management’s expectations for operating within established limits.

2.15.C Independent reviews should be performed on the implementation of the reactivity management programme.

2.15.D More guidance on the reactivity control during operations of nuclear power plants can be found in Ref. Conduct of operations at nuclear power plants, IAEA Safety Standards Series No. NS-G-2.14 [7]. Additional information on the core reactivity characteristics and means of control of reactivity can be found in Ref.[5].

CORE MONITORING PROGRAMME

2.16. ~~A comprehensive core monitoring programme should be established to ensure that the core parameters are monitored, analysed for trends and evaluated in order to detect abnormal behaviour, that actual core performance is consistent with core design requirements and that the values of key operating parameters are recorded and retained in a logical and consistent manner~~.Deleted.(R7.21)[CR18]

2.16.A. Key core parameters should be monitored in the control room continuously, with more detailed measurements taken at a suitable frequency during core operation to ensure that they remain within operational limits and conditions and that any corrective action can be taken when necessary.

2.17. With the reactor operating at power, core conditions should be monitored and compared with predictions to determine whether they are as expected and are within operational limits (see Ref. Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.2 [~~4~~8]). If the core conditions do not conform, appropriate action should be taken to maintain the reactor in a safe condition. The results of core monitoring and testing should also be applied to the review and updating of the refuelling programme and the optimization of core performance. The parameters to be monitored, either continuously or at appropriate intervals, analysed for trends and evaluated should include, but are not limited to, the following, as appropriate:

- Axial, radial and azimuthal neutron flux peaking factors;
- Rate of change of neutron flux;
- Positions and patterns of control rods and zonal neutron absorbers;
- ~~Poison~~ C~~c~~oncentrations of soluble boron or B-10 content when enriched boron is used in the coolant and/or moderator;
- Water level in the reactor vessel;
- Operability and response characteristics of devices for reactivity control and other significant means of controlling reactor power;
- Reactivity as a function of control rod position or moderator level;
- Scram time, dump valve opening time, dump time and absorber injection time following each reactor trip;
- Pressure, flow and temperature rise of the coolant and the coolant outlet temperatures in the primary and secondary circuits;
- Average zonal and/or sector coolant outlet temperatures and power tilt factors;
- Assessed values for:
  - (a) thermal power output from the core;
  - (b) fuel temperature;
  - (c) heat generation in the moderator;
  - (d) minimum critical power ratio;
  - (e) departure from nucleate boiling ratio;
  - (f) the limits on the linear heat generation rate;
- Moderator temperature and peak channel mass flow;
- Fission product activity in the primary coolant or the off-gas system;
- Physical and chemical parameters of the moderator and primary coolant, such as pH, conductivity, the amount of crud and the concentration of impurities and products of radiolytic decomposition;
- Isotopic composition of absorbers in coolant and moderator.

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

- Reactivity and control rod configurations are correct;
- Channel flows are correct;
- The pressure vessel and major structural components are performing normally;
- Coolant temperatures are as expected.

2.18.A Suitable instrumentation should be provided and maintained for monitoring the core parameters such as the core power (level, distribution and time dependent variation), the conditions and physical properties of the coolant and moderator (flow rate, temperature) and the expected efficiency of the means of shutdown of the reactor (e.g. the insertion rate of the absorber devices compared with their insertion limits), so that any necessary corrective action can be taken. The instrumentation to be used for core monitoring should be appropriately qualified~~. for normal operation and accident conditions~~ (see Ref.[5]).[CR19]

2.19. The instrumentation for monitoring the relevant parameters should normally be arranged so as:

- To have adequate range overlap at all power levels from the source range to full power;
- To have suitable sensitivity, range and calibration for all operational states and, where appropriate, for accident conditions;
- To provide the necessary information on the spatial variation in values of the core parameters needed for evaluation of its state;
- To facilitate the evaluation of core performance and the assessment of abnormal situations by the operators.

2.19.A In order to be able to detect control rod anomalies or reactivity control disturbances or degraded core cooling in all relevant reactor operation states, core monitoring should ensure the following[CR20]:

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

2.19.B For [CR21]load-following regimes, which increases the constraints on core equipment, the monitoring strategy should be appropriately adjusted. Monitoring of equipment fatigue should be performed (temperatures measured and recorded, non-destructive materials tests, etc.), especially on the safety related components. Special attention should be put on the monitoring of the control rod mechanisms and thermal and core parameters fluctuations.

2.20. Parameters such as coolant temperature, coolant pressure, coolant flow and neutron flux distribution 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 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 action in order to maintain the appropriate safety margins.

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

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

2.23. The values of parameters such as those related to chemical 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

General

2.24. The operating organization should ensure that the fuel has been adequately designed and has been manufactured in accordance with design specifications, and that only approved fuel is loaded into the core.

~~2.24.~~2.25. Prior to insertion or reinsertion, the fuel should be inspected in accordance with established acceptance criteria to ensure that damaged or failed fuel is not loaded into the core.

~~2.25.~~2.26. An effective fuel integrity monitoring programme should be established and implemented. This programme should include, but should not be limited to, the monitoring of fuel operating parameters, the use of lead test assemblies, the inspection of irradiated fuel and, in special cases, hot cell examinations. There should be a policy in the operating organization to identify the causes of any fuel failure.

~~2.26.~~2.27. The fuel integrity monitoring programme should include the appropriate procedures and engineering practices:

- To implement operating strategies that minimize the potential for fuel failures;
- To ensure that radiochemistry data indicative of fuel integrity are systematically analysed for trends and evaluated to detect anomalous behaviour;
- To implement an action plan for failed fuel.

~~2.27.~~2.28. The fuel integrity monitoring programme[GS22][CR23] should be developed so as to reduce radiation to levels as low as reasonably achievable (ALARA).

Fuel integrity monitoring

~~2.28.~~2.29. Deleted[GS24][CR25]~~To ensure that fuel cladding integrity is maintained under all core operating conditions, radiochemistry data that are indicative of fuel cladding integrity should be systematically monitored and analysed for trends. Appropriate methods should be established to identify any anomalous changes in coolant activity and to perform data analysis in order to determine~~:

- ~~The nature and severity of fuel defects;~~
- ~~The locations of fuel defects;~~
- ~~The probable root causes of fuel defects;~~
- ~~Recommended actions~~.

(R7.24and R7.25)

~~2.29.~~2.30. An ~~One~~ i~~I~~mportant indication of fuel failure is an increase in fission product activity above the normal value in the primary coolant (or the off-gas system). Monitoring of fission product activity in the coolant should be performed routinely by means of an on-line instrument, by measurement of the activity in samples or by both techniques. Investigations of particular radionuclides should~~may~~ be made to characterize failures.

~~2.30.~~2.31. The normal level of fission product activity in the reactor coolant should be specified during the initial period of reactor operation following startup in order to provide a reference background level.

~~2.31.~~2.32. For reactors designed for on-load refuelling, a reference level should be used to specify an upper limit criterion for the fission product activity in the reactor coolant above which a fuel failure will be assumed to have occurred. Where applicable, a scanning system (such as a delayed neutron monitoring system) should be put into operation in order to locate the failed fuel. If the scanning system has provisions for monitoring the coolant samples from a single channel and groups of channels, a specified value for the ratio of activity in a single channel to that in its group should be determined from experience for use as a criterion in deciding whether the channel contains failed fuel.

~~2.32.~~2.33. The integrity of all parts of the fuel assembly should be ensured by monitoring and operational assessment, where appropriate. In particular, highly stressed components in the lifting load path for on-load refuelling that are subject to temperature cycling or other stresses should be carefully examined and considered for long~~-~~term safety assurance.

Action planning for failed fuel

~~2.33.~~2.34. To ensure that the core operates within radiological limits and that corrective actions for failed fuel are taken, a fuel failure contingency plan or policy should be established and implemented. It should contain the following key elements:

- Action levels for investigation activities that focus on fuel failure;
- Action levels to restrict power operations in order to preclude additional fuel damage and to prevent exacerbation of any existing fuel damage;
- Measures to identify leaking fuel assemblies and to remove them from service;
- Measures to determine the cause of the loss of fuel integrity;
- Measures to remedy the cause of fuel damage;
- Fuel inspection activities;
- Fuel reconstitution activities;
- Review of lessons learned to prevent failures in the future stemming from the same root cause.

~~2.34.~~2.35. In the case of reactors designed for on-load refuelling, operating instructions should be established with indication of the predetermined levels at which corrective actions should be taken. Failed fuel should be unloaded so that the background fission product activity will remain low enough to permit detection of future failures, to minimize contamination of the coolant and the primary coolant circuit and to prevent subsequent fuel damage (such as damage due to the formation of oxide or hydride mounds). The refuelling plan should be reviewed to determine whether it should be modified as a result of unloading of the failed fuel.

~~2.35.~~2.36. Generally, reactors designed for off-load refuelling permit continued operation at power with some failed fuel. The criteria for shutting down the reactor to remove failed fuel are usually based on the maximum permissible off-gas activity or the maximum permissible fission product inventory in the coolant system in order to minimize the actual or potential exposure of site personnel and the public. In-core or out-of-core sipping tests are used to find failed fuel. Failed fuel should not be reused without its repair or reconstitution. The core design should be reviewed to determine whether changes are needed as a result of the removal of failed fuel.

Tracking of fuel history

~~2.36.~~2.37. The fuel history should be recorded in order to consider all relevant aspects of fuel performance, such as:

- Fuel design and operational characteristics;
- Fuel operating history, including information about any abnormal operating conditions;
- Burnup history and associated core locations;
- Coolant chemistry history;
- Nuclide inventory;
- The chronology of fuel cladding defects, including their initial indication, root cause evaluations and completion of corrective actions.

New designs of fuel or modifications to fuel

~~2.37.~~2.38. If fuel of a new design or modified fuel is to be introduced into the core, the operating organization will be responsible for ensuring that the safety related effects of this fuel on core operations are thoroughly investigated and understood. Prior to operating a core with fuels of more than one type, the operating organization should ensure that the fuel of new design or modified fuel is compatible with the existing fuel and that the core designer has access to all the relevant information.

~~2.38.~~2.39. The operating organization will be responsible for ensuring that all necessary safety evaluations of the new or modified fuel are performed, and that the new fuel meets the design requirements (see ~~footnote 1~~Refs.[3] and [5]). Appropriate licensing documentation should be prepared for the new or modified reload fuel. This documentation should include, but is not limited to, the following:

- Information on fuel design and input data for prediction and monitoring of core behaviour;
- Results of analyses and testing that were used to develop correlations for

monitoring thermal margins;
- Verification of mechanical, thermal-hydraulic and neutronic limits for design compatibility;
- Analyses of transients.

~~2.39.~~2.40. To assess the behaviour of fuel of new design or modified fuel under the conditions expected in subsequent reloads, a lead test assembly programme should be considered in which account should be taken of all available operating experience. Such a programme should include:

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

~~2.40.~~2.41. Experimental feedback and research and development programmes covering power ramp tests, reactivity initiated accident tests and loss of coolant accident tests (analytical or global) should be taken into consideration to demonstrate the behaviour of fuel of new designs under normal and accident conditions.

~~2.41.~~2.42. Consideration should be given to changes in the supplier of fuel. Care should be taken by the operating organization, in considering changing to a new supplier, to ensure the quality of the fuel assembly.

REFUELLING PROGRAMME

~~2.42.~~2.43. There should be strict control of core discharge, reload, shuffle or on-load refuelling, and all core alterations should comply with predicted configurations. Throughout such changes, core reactivity should be monitored to prevent an inadvertent criticality and all fuel movements should be in accordance with detailed, approved procedures. Intermediate fuel patterns should be no more reactive than the most reactive configuration considered and approved in the design (some reactors using natural uranium show a reactivity increase as plutonium builds up in the fuel during its early use). There should be a method of checking that fuel movements would not be in conflict with each other, and it should be possible to track back the actual fuel movements made if necessary.

~~2.43.~~2.44. The refuelling programme should include details of the core pattern and a schedule of movements of core components (fuel assemblies, control rods, burnable absorbers and flux shaping absorbers) into and out of the reactor. The necessary checks during refuelling to verify the correct performance of different activities should be also included in the refuelling programme.

~~2.44.~~2.45. In achieving design power and the target rate for fuel burnup, and in providing sufficient reactivity to compensate for fuel depletion and the buildup of fission products, the safety objectives of the refuelling programme shall be met throughout the lifetime of the reactor, starting from the initial fuel loading. These safety objectives should include the following:

- Maintaining neutron flux distribution and other core parameters within the applicable operational limits and conditions;
- Meeting the requirements for the shutdown margin.

~~2.45.~~2.46. The aspects that should be considered in the establishment and use of a refuelling programme should include, as appropriate:

- Fuel burnup and consequent structural and metallurgical limitations;
- Temperatures of coolant and fuel cladding in relation to flux distributions, channel flows and absorber configurations;
- Increase in power output from a fuel assembly either during on-load refuelling or while the reactor power is being raised (this may impose a restriction on the rate of rise of reactor power or may require a minimum time for holding the power constant before the next power increment);
- Avoidance of unacceptable flux tilts and reactor instability;
- Assurance of the mechanical capability of fuel elements to withstand reactor core conditions and refuelling operations, particularly for shuffling and reuse of irradiated fuel elements;
- Availability and capability of refuelling machines (for reactors designed for on-load refuelling);
- Special considerations which may necessitate restrictions on particular fuel assemblies, such as limitations of the power output;
- Changes arising from the removal of failed fuel and the insertion of fresh~~new~~ fuel assemblies (such as changes in local temperatures and changes in reactivity);
- Selection of channels for on-load refuelling to maintain radial symmetry and, in the case of bidirectional refuelling, axial symmetry;
- Positioning of unirradiated and irradiated fuel in the core, its enrichment and ~~poison~~ neutron absorber levels being taken into consideration;
- Depletion of neutron absorbers in control rods and of burnable absorbers;
- Highest reactivity worth of an individual control rod that could remain inoperable in the fully withdrawn position;
- Deviations of actual core operating parameters from the nuclear calculations used in the refuelling programme (these necessitate consideration of control rod and absorber configurations, fuel burnup, neutron flux distribution and depletion of neutron absorbers~~ and burnable absorbers)~~;

- Changes due to thermal shock and changes in reactivity during on-load refuelling.

~~2.46.~~2.47. After off-load refuelling of a reactor, the core conditions should be assessed before startup to verify that the operational limits and conditions and shutdown margins will be met throughout the reload cycle. Shutdown capability should be confirmed by appropriate testing.

~~2.47.~~2.48. For reactors that are refuelled on load, the criteria governing the refuelling programme should be set out and compliance with all applicable operational limits and conditions should be verified. If there are significant deviations from the established programme, a safety assessment of the new core conditions should be made and any necessary actions should be taken.

~~2.48.~~2.49. The predictions of core behaviour required for the assessments mentioned in paras 2.47 and 2.48 are discussed in paras 2.4–2.6. Calculated simulations with current reactor data should be used to update assessments of core performance and to plan the subsequent refuelling programme. In addition, other data such as those on fuel burnup rates, reactivity, power density and neutron flux distributions should~~may~~ be obtained in simulations.

~~2.49.~~2.50. For on-load refuelled reactors,~~ it is useful, where appropriate, to have~~ information on fuel scheduling, including a list of channels containing fuel and the corresponding burnup should be available. The selection of channels for refuelling should take into account this information and other considerations, including those mentioned in paragraph 2.46.

~~2.50.~~2.51. In off-load refuelled reactors, it is normal to have control rods in the core during startup and load changes and at steady power. The refuelling programme should specify the control rod patterns and sequencing that satisfy the requirements for control rod reactivity worths and power distribution.

~~2.51.~~2.52. Checks should be performed after a reload to provide assurance that the core has been correctly constituted. In addition, physics tests should be performed before or during startup after each reload to verify the constitution and characteristics of the core, and control rod reactivity worths and boron worths throughout their operating range. Tests should include, but should not be limited to, the following, as appropriate:

- Withdrawal and insertion of each control rod to check for operability;
- Control rod drop times;
- Demonstration that, if the control rod with the strongest worth is in the fully withdrawn position, the core meets the specification for shutdown margins;

- Comparison of predicted and measured critical rod configurations for non-voided conditions in accordance with planned rod withdrawal sequences;
- Measurement and assessment of the moderator temperature coefficient and other temperature coefficients of reactivity, critical boron concentrations and rod bank worths;
- In-core flux mapping and core symmetry checks using either symmetric control rods or in-core instrumentation;
- Comparison of measured and calculated flux distributions and power distributions;
- Confirmation of core power symmetry by checking for mismatches between measurements.

2.52.A. The test results should be reviewed independently by competent reactor physics expert(s).

SURVEILLANCE RELATING TO CORE MANAGEMENT AND FUEL HANDLING

~~2.52.~~2.53. A core management and fuel handling surveillance programme should be established for the early detection of any deterioration that could result in an unsafe condition in the reactor core. Surveillance activities should include monitoring, checking, calibration, testing and inspection. These activities should be part of an over-all surveillance programme to be formulated and implemented according to the recommendations given in Ref. Maintenance, Surveillance and In-Service Inspection of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.6 [~~5~~9]. The following items that are particularly relevant to core management and fuel handling should be covered in the surveillance programme:

- Protection and control systems (operability, actuation times and reactivity change rates);
- Instrumentation for measurement of parameters necessary for core monitoring (see paragraph 2.19);
- Core cooling systems, including the cooling of core components (flow rate, pressure, temperature, activity and chemistry of the coolant);
- Handling systems for fuel and core components (including instrument and interlock checks);
- Degradation of fuel and other core components, such as bowing effects of fuel assemblies and fretting, wear-out and swelling of control rods.

2.53.A The equipment qualification programme of the plant should be in place to confirm the capability of the instrumentation and systems used for the core monitoring, fuel handling and storage to perform their function, for the relevant time period, taking in~~with~~ account ~~taken of~~ the appropriate functional and safety considerations under given environmental conditions [CR26](e.g. conditions of pressure, temperature, radiation levels, mechanical loading and vibration). ~~These environmental conditions should include the variations expected in normal operation, anticipated operational occurrences, design basis accidents and design extension conditions without significant fuel degradation.~~

FOREIGN MATERIAL EXCLUSION (FME) ARRANGEMENTS FOR FUEL HANDLING

2.53.B The plant FME programme should include provisions to ensure the exclusion of foreign materials when performing specific activities near /or on the fuel or fuel containing facilities in order to prevent immediate or latent fuel damage or loss of integrity. Specific attention should be paid to the maintenance activities, in particular during the outages, on the opened main cooling circuit systems and components, reactor vessel cavity and spent fuel storage. The appropriate FME requirements should be established and maintained for all operations with the fresh and irradiated fuel. Fresh fuel should be inspected as per the site-specific procedure to ensure foreign material is not present.

2.53.C The specific FME area should be established around the places where fuel handling activities are planned. A FME zone should be appropriately labelled and designated by boundary items (stanchions), or ~~use an established~~ a barrier around the specific working place (contamination control barrier) established. A buffer area should be identified by designated markings on the floor around the FME zone to minimize the potential for foreign material intrusion. The storage of tools, equipment, or materials within the buffer zone should be minimized.

2.53.D The necessary clean working conditions should be created at the places where fuel handling or fuel repair operations are in progress to prevent foreign material from entering the opened cavities. This should be accomplished by taking only necessary materials into and around the FME area, maintain positive control of all materials, and then removing them from the area as soon as possible. An empty pockets policy should be implemented if working in close proximity to spent fuel pool or opened reactor vessel cavity handrail. All materials and tools entering the FME zone should be logged in and out of a tool and material control log. A logbook should be located at the entrance of the FME zone. All items and materials should be removed from the FME zone at the end of each shift, unless approved and documented to do otherwise.

3. HANDLING AND STORAGE OF FRESH FUEL

MANAGEMENT OF FRESH FUEL

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

3.2. The principal elements of any fresh fuel handling programme should include receipt, transfer, inspection and storage of nuclear fuel. A well-structured programme should adopt a methodical approach that is administratively controlled by procedures and engineering practices. The purposes of this programme are:

- To delineate physical boundaries within which fresh ~~nuclear~~ fuel[GS27][CR28] is to be stored and which are subject to practices for material control and constraints on the criticality configuration;
- To meet administrative requirements and to provide technical instructions for fresh fuel inspections, including contingency actions for damaged fuel.

3.2.A Specific attention [CR29]should be taken for handling fresh mixed oxide (MOX) fuel since ~~the mixed oxide fuel~~it has a higher radiation level and higher heat generation in comparison to ~~the~~ fresh UO_2 fuel.~~. In particular during MOX fuel.~~ ~~inspections~~Shielding measures should be taken to reduce radiation exposure.

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

3.4. Overriding of automatic safety systems (such as overload or alignment interlocks) should be prohibited in normal fuel handling procedures. Under abnormal fuel handling conditions, an urgent need may arise for defeating interlocks. Such operations should be carried out by competent and authorized staff only, in accordance with approved procedures. An independent safety review of such actions should be performed before ~~such~~these abnormal operations are commenced.

3.5. To reduce the possibility of causing damage to fuel during handling, only equipment designed for handling fuel should be used, see Ref.[16].~~[3]~~ ~~[2]~~Personnel engaged in handling fuel should be suitably qualified and formally trained and should work under the supervision of an authorized person. All activities relating to the fresh fuel should be performed in accordance with the approved procedures. Key operations should be verified and signed off in confirmation by authorized personnel.

~~3.5.~~3.6. Any fuel suspected of being damaged during handling or storage should be inspected and, if necessary, treated in accordance with the established procedures relating to damaged fuel (see paragraph 3.17).

~~3.6.~~3.7. When fuel is handled manually, suitable ~~clothing should be worn~~protective equipment and clothings~~s~~ should be used to prevent contamination of personnel (see Ref. Radiation Protection and Radioactive Waste Management in the Operation of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.7 [~~6~~10]) and to prevent damage to or contamination of the fuel cladding.

~~3.7.~~3.8. If fuel is to be transported between buildings on the site, suitable and appropriately labelled ~~containers~~ casks and packing should be used to prevent contamination of or damage to the fuel. The routes for all fuel movements should be kept as short and simple as possible.

~~3.8.~~3.9. The areas for the handling and storage of fresh fuel should be maintained under appropriate environmental conditions (in respect of humidity, temperature and clean air) and controlled at all times to exclude chemical contaminants and foreign materials.

~~3.9.~~3.10. The handling and storage areas for fresh fuel should be secured against unauthorized access and unauthorized removal of fuel. A storage area should not be part of an access route to other operating areas.

~~3.10.~~3.11. Heavy loads may endanger items important to safety if dropped and should not be moved above stored fuel (in racks, storage canisters or lifting devices). Exemptions should be justified.

~~3.11.~~3.12. The equipment used to check the physical dimensions of the fuel should be periodically recalibrated. Fuel handling equipment and associated systems should be checked periodically, or at least before a refuelling campaign, and maintained.

~~3.12.~~3.13. To ensure that under all circumstances fuel assemblies may be readily placed in a safe location during handling, manually operated equipment for emergency operations should be provided.

~~3.13.~~3.14. Fresh fuel giving rise to higher radiation levels (as in the case of fuel containing reprocessed materials) should be handled in accordance with procedures designed specifically to reduce doses to personnel.

~~[3] [2] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Fuel Handling and Storage Systems for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.4, IAEA, Vienna (2003).INTERNATIONAL ATOMIC ENERGY AGENCY, Design for Reactor Core Safety in Nuclear Power Plants, Safety Series No. 50-SG-D14, IAEA, Vienna (1986) (to be superseded by a Safety Standards Series publication on safety of the reactor core in nuclear power plants).~~

RECEIPT OF FRESH FUEL

~~3.14.~~3.15. Before fuel is received, the operating organization should make arrangements to ensure that a designated person is responsible for the control of the fuel on the site, and that access to the fuel storage area is limited to authorized personnel only.

~~3.15.~~3.16. Fuel should be received, unpacked and inspected by trained and qualified personnel in accordance with written procedures for the identification of damaged fuel. The reception and unpacking of fresh ~~nuclear~~ fuel should take place in an area that is designed for fuel handling. There should be an inspection programme for fresh fuel to check the external appearance of the fuel and to check for any damage during transport~~ (drop, earthquake, accident…)~~. Inspection of the fuel should include checking of specified parameters (such as dimensions) which may have been affected by transport and handling since the supplier’s final inspection. The 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.

~~3.16.~~3.17. The written procedures for the identification of damaged fuel should be reviewed if fuel of a new design is to be brought onto the site. Acceptance criteria should be available for assessing damaged fuel. A record should be made of any damage accepted by the examiner. Rejected fuel should be treated as non-conforming in accordance with ~~quality assurance recommendations specified in the IAEA Safety Standards publication Application of the Management System for Facilities and Activities provisions~~ Ref.[~~3~~4]~~ in particular Safety Guides Q6 and Q7)~~. The root causes of any failures should be investigated and corrective measures should be taken to prevent their recurrence.

~~3.17.~~3.18. Transport ~~containers~~ casks [GS30][CR31]should be checked to verify that they are properly identified and free from damage. Storage arrangements and identification should be such as to eliminate unnecessary handling.

~~3.18.~~3.19. Inspections should neither damage the fuel nor introduce any foreign material into it. Inspectors should identify any foreign material already present in the fuel and should remove it.

~~3.19.~~3.20. If, following inspection, fresh fuel assemblies have to be repaired, the fuel supplier should be involved in any proposed repair or modification. Technical and administrative precautions should be taken to ensure that only the specified fuel assemblies are repaired, that the repair work is carried out in accordance with written instructions (relating, for example, to the position, enrichment and poison content of the fuel elements) and that no critical configuration is created.

STORAGE OF FRESH FUEL

~~3.20.~~3.21. Proper receipt, storage and handling facilities to accommodate the full consignment of fuel should be available on the site before any fresh fuel is delivered to the site. If fuel of a new design is to be delivered, the fuel enrichment has changed or re-racking of a storage area is necessary, the validity of the criticality safety analysis[GS32][CR33] should be reassessed before receipt of the fuel. A Safety Guide on fuel handling and storage systems in nuclear power plants (see Ref. Design of Fuel Handling and Storage Systems for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.4 [15~~6~~]~~see footnote 3~~) ~~will~~ provides information on the design aspects of such facilities and will consider internal and external events that could lead to inadvertent criticality excursions or could adversely affect the fuel and/or fuel handling and storage systems.

~~3.21.~~3.22. Adequate and specified storage positions should be available to ensure the integrity of fuel assemblies and to prevent them from being damaged. In particular, appropriate measures should be taken to avoid axial twisting of the fuel assemblies.

~~3.22.~~3.23. The storage area for fresh fuel shall meet the subcriticality requirements specified in the design (see Ref.[15~~6~~]~~see footnote 3[2]~~) and shall be kept subcritical at all times, even in the event of internal or external flooding or any other event considered in the design. Physical and/or administrative measures should be taken to ensure that fuel is handled and stored only in authorized locations in order to prevent a critical configuration from arising. It should be verified that the fuel's enrichment is commensurate with the design limitations of the storage area.

~~3.23.~~3.24. A dry fresh fuel storage area should be clear of any equipment, valves or piping that undergo periodic surveillance by operating personnel.

3.25 For a wet fresh fuel storage area the water conditions and rack layout should be maintained within specified limits to ensure the subcriticality margins. Moreover, strict observance of the requirements for water chemistry should minimize the corrosion of the fuel cladding and the storage components (see also paragraph 5.13).

3.26. For wet and dry storage systems that use ~~fixed solid~~ neutron absorbers, a lifetime surveillance programme should be put in place to ensure that the absorbers are installed and that they have not lost their effectiveness or been displaced.

3.27. When fuel assemblies are stored outside their sealed transport ~~containers~~ casks[GS34][CR35], the ventilation system should be used to prevent dust and other airborne particles from entering the fresh fuel storage area. One way to achieve this is to use filters in the inlet air channel and to keep the ambient air pressure of the storage area slightly higher than that of the surrounding areas.

3.28. Drains in dry storage areas for fresh fuel should be properly kept clear for the efficient removal of any water that may enter and they should not constitute a possible cause of flooding.

3.29. Fire risks in the fuel store should be minimized by preventing the accumulation of combustible material in the storage area. Instructions for fire fighting and fire fighting equipment suitable for use in case of fires involving fuel should be readily available. There should be set procedures for controlling the transfer of moderating material into the fresh fuel storage area to ensure that subcriticality will always be maintained, even if fire extinguishing materials are used. More information on fire safety can be found in Ref. Fire Safety in the Operation of Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.1 [~~7~~11].

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

3.31. Before the first fuel is delivered to the fuel storage area, the relevant parts of the radiation protection programme should be in effect and adequate emergency preparedness and response ~~plans~~ arrangements implemented and tested (see Ref.[~~6~~10]).[CR36][CR37]

4. IMPLEMENTATION OF THE REFUELLING PROGRAMME

PREPARATION

4.1. The refuelling programme described in paragraphs 2.43–2.52 should be implemented by means of refuelling plans that specify in detail the sequence of the operations to be carried out. The refuelling plans should specify the types of fuel and core components to be withdrawn from the storage areas, the route they are to take and the positions they are to occupy in the core. The plan should also specify: which fuel is 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 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 in confirmation by an authorized person.~~

4.2. The steps necessary to assemble fresh fuel and to prepare it for use in the reactor should be specified in the procedures, including any arrangements for holding it in intermediate storage. Only approved fuel should be loaded into a reactor core. Checks should be carried out to confirm that the fuel has been assembled correctly. In all procedures for fuel handling and maintenance, it should be ensured as far as possible that no foreign material is introduced into the reactor.

4.3. Reliable ~~two~~ three- way[3] communication should be available at all times between the fuel handling staff and the control room staff.

LOADING FUEL AND CORE COMPONENTS INTO THE REACTOR

4.4. When fuel is moved from storage, it should be identified and checked against the approved refuelling 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 has been loaded into the specified position in the core and correctly positioned (and, in the case of light water reactors, with the specified orientation). Any subcriticality checks to be performed during off-load refuelling should be specified in the refuelling procedures.

4.5. Although handling procedures may be simpler when a reactor is being loaded for the first time, since the fuel and core components have not yet been irradiated, the refuelling plans and the quality assurance procedures referred to earlier in this section should still be followed. Checks should also be carried out before fresh fuel is loaded into the refuelling machine or the core to see that all equipment, materials and dummy or test fuel assemblies used for commissioning have been removed. Precautions should also be taken to prevent items from entering the reactor core. Dummy or test fuel assemblies should be clearly distinguishable, even when in the core. Procedures, including documented procedures, should be followed to ensure that all unnecessary material has been removed from the reactor vessel before it is closed. For guidance on the first fuel loading, see Ref. Commissioning of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-28 [~~8~~12].

4.6. Requirements and procedures should be in place to test the fuel transfer

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

machine and any other tool or system that may be necessary before the commencement of fuel loading. The loading personnel should be qualified and trained. Loading machine operators should be licensed in accordance with local regulations. Personnel should be trained on the fuel transfer machine, initially using dummy fuel, and should be trained to carry out operations for the entire route travelled by fuel from the reception point to the reactor cavity and the spent fuel pit.

4.7. Any core component (instrumentation, coolant flow orifice plate, plug, control rod and neutron absorber) that forms part of or is attached to a fuel assembly should be inspected and checked as part of the refuelling procedure in accordance with the quality assurance requirements. Any safety aspects relating to neutron source assemblies and core components that have not been taken into account in the fuel loading plan should be considered before these assemblies and components are loaded into the reactor core.

4.8. There should be set procedures for controlling the movement of any core component into or out of the core. Checks should be incorporated, where possible, to ensure satisfactory insertion of the fuel. For an item that is not part of the design as described in the safety analysis report and is not a permanent part of the plant (such as samples of materials to be irradiated), the procedure should require a thorough safety review of that item and appropriate approval for its movements into and out of the core and its residence in the core.

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

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

UNLOADING FUEL AND CORE COMPONENTS

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

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

4.13. For purposes of radiological protection, precautions to be taken in handling unloaded fuel, core components and materials and 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 temporarily) irradiated or contaminated items in order to avoid the spread of contamination or the risk of undue radiation exposure.

4.14. If conditions warrant it, and if any physical damage is suspected, unloaded fuel and core components should be examined before storage. Discovery of damage to fuel or core components should~~may~~ require examination of adjacent components. Any repairs should, ideally, be based on proven techniques and carried out in accordance with an approved method.

4.15. Any fuel that is known to have failed should be treated in a suitable way to reduce storage facility contamination and to enable compliance with the applicable transport requirements when it is subsequently shipped off the site. Any fuel that is suspected to have failed should be treated as failed fuel until a thorough check shows that it is intact.

4.16. Before the rack locations in the storage facility receive unloaded fuel, they should be examined if it is suspected that there could be damage which could affect the integrity of the fuel[GS38][CR39]. Racks should be kept within specified vertical tolerances to ensure that fuel assemblies are not distorted.

PRECAUTIONS FOR LOADING AND UNLOADING FUEL AND CORE COMPONENTS

4.16.A[CR40] ~~It should be ensured b~~By means of ~~the proper~~ appropriate handling and storage of ~~fresh~~ new [CR41]fuel, it should be ensured that fuel integrity is preserved at all times.~~, and the~~ The means to check the condition of the fuel prior to its use should be provided in order to minimize the risk of inserting damaged fuel into the reactor.

4.17. The procedures for the implementation of the established refuelling plan should include the necessary precautions to ensure safety. Aspects such as reactivity status, component integrity, heat dissipation and radiological protection including shielding should be considered. Examples of issues to be considered during fuel handling and the handling of other core component are:

- Criticality arising, for example, from errors while manipulating reactivity control devices;
- Physical damage to fuel resulting from bumping or dropping of components;
- Damage to fuel due to distortion, swelling or bowing of fuel assemblies or fuel

elements;
- Personnel exposure due to the radioactivity of components or material released during handling.

4.18. For off-load refuelled reactors, prerequisites for ensuring that a critical configuration is not formed during fuel loading, such as nuclear startup instrumentation and protection system interlocks, should be checked before and, as appropriate, during the loading process. This is particularly important during the first core loading. More information on the prerequisites and test conditions can be found in Ref.[~~8~~12].

4.19. The following are examples of specific issues which should be taken into consideration for reactors that are refuelled off-load[4]:

- Measures for radiological protection and supervision during the refuelling process should be established;
- Containment or confinement integrity should be as specified for refuelling;
- Air cleaning systems should be operable as specified;
- A reliable power source should be available~~;~~;
- Startup range neutron flux detectors and related alarms should be operable;
- Control rods should be inserted into the core and disconnected to render them inoperable, borated water with the specified boron concentration should be circulated and positive measures should be taken to prevent dilution (lockout of pure water control valve; locking of all borated water systems likely to be used in the vicinity of the reactor);
- The reactor vessel and pool storage water levels should be maintained above specified minimum levels;
- The reactor should be subcritical for a minimum specified period and by a minimum amount before fuel discharge is commenced;
- Appropriate interlocks should be in the correct configuration and the necessary functional checks and calibrations should be carried out on the control rod drive circuit, the reactor protection system and the refuelling equipment;
- At least one shutdown cooling loop should be in operation with appropriate emergency cooling capability available;
- Appropriate procedures should be established to prevent foreign materials from being introduced into the reactor vessel;
- Measures should be taken to prevent any unnecessary handling of components or tools over the reactor pool while handling a fuel assembly;
- Adequate communication links should be established between the control room and the fuel loading area;

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[4] The list takes into account the considerations for a light water reactor design. Similar lists may be prepared for other types of reactors that are refuelled off-load.

- An authorized person should be in charge throughout the entire refuelling process;
- A final check should be carried out before vessel closure to ensure that the core has been correctly loaded (checking fuel and core component identification) and, if possible, a video recording should be made for subsequent verification;
- Emergency procedures should be provided for fuel handling faults.

4.20. Similarly, for reactors that are refuelled on-load, the following issues should be taken into consideration:

- Reactor operating conditions should be established and should be stable at the level pertaining to the refuelling;
- All monitoring instrumentation and safety devices necessary for safe and correct refuelling should be calibrated and confirmed to be in service and operating satisfactorily;
- It should be confirmed that the correct fuel assemblies are collected from the right storage locations and loaded into the appropriate magazine of the refuelling machine, and space should be available in the magazine to receive the unloaded fuel;
- Commencement of refuelling should be authorized by control room operators, who should be kept informed of the state of refuelling;
- Independent checks should be made to ensure that the refuelling machine is properly connected to the correct fuel changing location (for bidirectional refuelling designs, it should be ensured that both the loading and unloading machines are aligned on the same channel before clamping);
- The refuelling machine should be operated by authorized persons only and special dispensation should be granted if any abnormal mode of operation is necessary (interlocks should only be overridden if specifically authorized on each occasion);
- In the refuelling machine, alternative means of plugging the reactor channel should be available if the new fuel assembly cannot be used;
- The refuelling machine should be capable of penetrating and reinstating the reactor containment boundary;
- Before disconnecting the refuelling machine from the fuel channel, it should be confirmed that the closure plug has been properly replaced;
- Satisfactory replacement of the closure plug should be checked before significant coolant pressure is established after refuelling in the depressurized state;
- Administrative controls should be in place to supplement design provisions against movement of the refuelling machine while it is connected to the reactor;
- Controls should be established to ensure that irradiated fuel in the machine is properly discharged before the coolant supply to the machine is stopped and, where appropriate, to prevent movement of the machine outside its design

range;

- Strict adherence to procedures should be ensured by techniques such as automatic control and/or use of checklists;
- The refuelling machine should be capable of accessing an area for maintenance when the reactor is operating;
- Facilities should be provided for testing the refuelling machine under conditions as representative as possible of actual operation;
- Emergency procedures should be in place for faults in fuel handling.

5. HANDLING AND STORAGE OF IRRADIATED FUEL

GENERAL OBJECTIVES

5.1. Fuel which has been exposed in the reactor is a radiation source and also contains fission products that should be retained in the fuel structure. The main safety objectives associated with the handling and storage of irradiated fuel are:

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

HANDLING OF IRRADIATED FUEL

5.2. In order to ensure that fuel integrity and subcriticality are maintained, irradiated fuel should be handled, stored and inspected only in approved facilities and with equipment qualified for this purpose (see Ref.[15~~6~~]~~footnote~~ ~~[3]~~), and only in accordance with written procedures. Further guidance is provided in ~~on the operation~~ ~~of spent fuel storage facilities can be found in~~ Ref. Storage of Spent Nuclear Fuel, IAEA Safety Standards Series No. SSG-15-[~~9~~13].

5.3. All movements of irradiated fuel should be performed in accordance with written procedures. ~~Key operations should be verified and signed off in confirmation by authorized personnel. The equipment used for the movement of irradiated fuel should be qualified and tested before use.~~ A system should be in place to account for the nuclide inventory and the decay heat of the irradiated fuel, if relevant.

5.3.A Before starting handling the irradiated fuel, the operability of all fuel handling and transfer equipment should be confirmed. This equipment should include, but is not limited to, the following:

- Fuel handling machines;
- Fuel transfer equipment;
- Fuel lifting devices;
- Means of assembling, disassembling and repairing fuel;
- Handling devices for all operations associated with transport of casks or inspection of spent fuel or casks;
- Provision for the safe handling of degraded or failed fuel or casks;
- Load measurement devices, including the overload protection;
- Illumination equipment;
- Appropriate shielding devices;
- Relevant radiation protection equipment;
- Decontamination devices;
- Instrumentation and control systems;
- Communication equipment.

5.4. Residual heat from irradiated fuel should be removed at a rate sufficient to prevent unacceptable degradation of the fuel assembly and of the storage and support systems which could result in the release of radioactive materials. The increased evaporation rate of pool water should be taken into account.

5.5. The spread of contamination should be controlled and minimized to ensure a safe operational environment within the plant areas and to prevent unacceptable releases of radioactive materials. For this purpose, dedicated equipment and procedures should~~may~~ be provided~~necessary~~ to cope with damaged or leaking fuel.

5.6. Shielding should be provided around all areas in which irradiated fuel or activated core components may be placed. This is necessary to protect ~~operators~~ staff and to ensure that their exposure to direct radiation from fission products and activated materials is kept as low as reasonably achievable, Ref. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards General Safety Requirements IAEA Safety Standards Series No. GSR Part 3 [~~10~~14].

5.7. Coolant chemistry should be controlled to prevent the deterioration of fuel material for all postulated conditions and to ensure subcriticality.

5.8. The handling and storage areas for irradiated fuel should be secured against unauthorized access or unauthorized removal of fuel. Core components intended to be handled or stored in areas for irradiated fuel should be managed in a specified and safe manner.

5.8.A Special, non-routine activities related to irradiated ~~nuclear~~ fuel[GS42][CR43] (e.g.

fuel cleaning / crud-removal operations, recovery of damaged fuel, application of special fuel inspection stands, etc.) should be planned carefully and implemented following established procedures. Detailed safety analysis should be performed and reviewed independently. Operating and~~on and~~ emergency procedures should be prepared and staff trained. The roles and responsibilities for the implementation and supervision of the activities should be established and continuous radiation level monitoring should be ensured. The operations should be carried out in such a manner that critical safety functions (i.e. subcriticality, residual heat removal and confinement of radioactivity[CR44]) are always maintained and radiation protection rules are fully observed.

5.9. Appropriate [GS45][CR46]emergency operating procedures and Severe Accident Management Guidelines should be established to manage anticipated events and ~~design basis~~ accident conditions~~s, design extension conditions without significant fuel degradation and external conditions exceeding the design basis~~ in the handling and storage of irradiated fuel[CR47]. These procedures and guideliness~~s~~ should cover events arising within the plant (e.g. criticality, loss of heat removal, dropped loads, internal fires and floods, ~~operator~~ human errors and failures of safety related systems) and those events external to the plant (e.g. seismic events, flooding, high winds and tornadoes and loss of off-site electrical power or a combination of co-related events~~them~~). More information on accidents in fuel handling and storage can be found in Refs.[~~11~~13~~5~~] and [~~,~~15~~6~~] ~~(see also footnote 3[2])~~. The Ref. Severe Accident Management Programmes for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.15[GS48][CR49] [19], provides recommendations for the development and implementation of emergency operating procedures and severe accident management guidelines during all modes of operation for the reactor, the spent fuel pool and or any other location of fuel[GS50][CR51].

STORAGE OF IRRADIATED FUEL

5.10. Adequate and specified storage sites should be used for the storage of irradiated fuel. Procedures should be used to ensure that the irradiated fuel is only stored in fully assessed configurations, and fuel storage analyses should consider, for example, new fuel designs, extended burnups and storage configurations for new fuel. More guidance on fuel storage analyses can be found in Ref.[~~11~~13~~5~~].

~~5.10.~~5.11. In particular, conformance with approved configurations, with the requirements for neutron absorbers in the storage facility and, where appropriate, with the maximum capacity is necessary. Specified neutron absorbers may be fixed absorbers or, for pool storage, boron in the water. A surveillance programme should be in place to ensure the integrity of the neutron absorbers~~ in the spent fuel pool~~. Suitable quality assurance procedures should be implemented to ensure subcriticality.

5.12. Reliable removal of residual heat should be ensured to prevent unacceptable degradation of the fuel assemblies which could result in a radioactive release. It should be ensured that the bulk temperature of the pool water as well as variations and rates of change of temperature are maintained within acceptable limits, as specified in the design requirements (see Ref.[~~12~~13]).

~~5.11.~~5.13. ~~5]).~~ 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 the heating, ventilation and air conditioning systems should be ensured.

~~5.12.~~5.14. For storage under water, water conditions should be maintained in accordance with specified values of temperature, pH, oxidation reduction reaction (redox, activity and other applicable chemical and physical characteristics) so as:

- To avoid the corrosion of fuel, core components and structures in the pool by maintaining suitable pH values and other applicable chemical conditions~~ (for example, halogen ion concentration)~~;
- To avoid boron crystallization by maintaining pool temperatures above a minimum level;
- To reduce contamination and radiation levels in the pool area by limiting water evaporation and water activity;
- To facilitate fuel handling in the pool by maintaining water clarity (removal of impurities and suspended particles) and providing adequate underwater illumination;
- To prevent boron dilution in pools where soluble boron is used for criticality control.

~~5.13.~~5.15. To avoid damage to fuel stored in the storage pool, the movement of heavy objects that are not part of the lifting devices above stored fuel should be prohibited unless specifically authorized on a case by case basis. All lifting should be restricted to the minimum height necessary to complete the operation safely. The pool crane should be checked prior to the start of fuel handling to ensure correct operation.

~~5.14.~~5.16. Storage areas should be kept under surveillance for radiological protection purposes (see Ref.[~~6~~10]~~, Section 3~~). Access should be limited to authorized personnel with appropriate training and all operations should be performed in accordance with approved written procedures.

~~5.15.~~5.17. Examples of the precautions that should be taken ~~with pool storage~~ to limit radiation exposures for pool storage include:

(1) The pool water level should be maintained between specified levels, leakage should be monitored and level alarms should be tested;
(2) Radiation monitors should be checked for operability and correct adjustment to ensure that they give an alarm if the radiation levels reach the alarm setting;
(3) Radiation levels at the water surface should be limited by the use of approved procedures and tools to ensure that fuel is not raised too close to the water surface;
(4) The ventilation system should be operated correctly to ensure that levels of airborne contamination remain within limits;
(5) Adequate communications should be provided between the pool area, the control room and radiation protection staff;
(6) There should be proper supervision and work control procedures (with the use of radiation work permits), adequate training should be provided, and dose history records and medical records of personnel should be kept;
(7) Access to the fuel pool area should be controlled.

~~5.16.~~5.18. For dry storage or storage under liquids other than water, appropriate safety procedures should be established.

~~5.17.~~5.19. For some reactor types, such as ~~pressurized water reactors~~ PWRs[GS52][CR53], it is important for safety purposes to retain sufficient capacity in the storage facility for irradiated fuel to accommodate the fuel inventory of the reactor and one full set of control rods at any given time (see Ref.[15~~6~~]~~also footnote 3~~2).

~~5.18.~~5.20. A policy for the exclusion of foreign materials should be adopted for all storage of irradiated fuel. Procedures should be in place to control the use of certain materials such as transparent sheets, which cannot be seen in water, and loose parts (see also paragraphs~~§§~~ 2.53A~~(b) –~~2.53D~~(d)~~).

~~5.19.~~5.21. Plans should be prepared for dealing with damaged or leaking fuel assemblies and appropriate storage arrangements should be made for them, such as:

- Storing leaking or damaged assemblies separately from other irradiated fuel;
- Providing containers (together with space in which to store them) capable of retaining a severely damaged assembly and any fragments, yet permitting adequate cooling;
- Providing containers for failed rods removed from assemblies that can be used either for long-~~-~~term storage, or for transport off the site.

INSPECTION OF IRRADIATED FUEL

5.21 In order to follow up the performance of fuel elements in the core and to predict their further behaviour, a programme for inspection of the irradiated fuel should be established. This is especially important when the unloaded fuel is to be reused in subsequent cycles. The results of inspection are also important in ensuring the integrity of the fuel finally dispatched, investigating the root causes of leaking fuel and providing feedback to the fuel vendor. Examples of the attributes of such a programme could be:

(1) Selection of fuel assemblies to be followed up and examined periodically throughout their period in the core and in storage as irradiated fuel (consideration may also be given to including some assemblies for post-irradiation examination);
(2) Use of lead test assemblies for testing new fuel designs and for increasing burnup, and a follow-up programme for such fuel in hot cells to study structural behaviour;
(3) Established arrangements for feedback and exchange of information with the fuel vendor.

5.22. Inspections should be performed in appropriate locations with equipment and procedures designed for the purpose, and the results should be recorded.

5.23. Appropriate space should be provided to carry out the required inspection, identification, dismantling and reconstitution of fuel, including burnup measurements, where necessary.

6. HANDLING AND STORAGE OF CORE COMPONENTS

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

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

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

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

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

- Irradiated core components should be stored only in special locations in the storage area designed for the purpose, and care should be taken not to store irradiated core components in the area for fresh fuel or in other clean storage areas;
- Adequate cooling should be provided;
- Access should be limited and shielding should be fitted to provide radiological protection;
- The material of the core component and the storage medium should be compatible;
- A component which is to be reused or which needs to be retrieved for other reasons should be accessible;
- Where inspection of irradiated components is necessary, interlocks should be provided and other appropriate measures taken to protect the operators from exposure;
- Means of transferring irradiated components into a suitable shipping ~~container~~ cask [GS54][CR55]should be provided where necessary.

6.6. An appropriate space should be provided for storage and use of the tools and equipment necessary for repair and testing of the core, without impairing the required storage capacity. Space for the receipt of other core components may also be necessary.

6.7. Active neutron sources available at the reactor site in any form should be shielded and should be treated appropriately. Adequate arrangements should be made for the clear identification of all sources and administrative procedures should be in place for controlling all sources. Contamination checks should be performed following the receipt of transport ~~containers~~ casks [GS56][CR57]containing neutron sources. The transport ~~containers~~ casks for neutron sources should be clearly marked in accordance with the requirements. ~~of the regulatory body~~[CR58]~~.~~

6.8. Where appropriate, programmes should be established for the surveillance and maintenance of core components during service. Checks should be made for physical changes such as bowing, swelling, corrosion, wear and creep. These programmes should include examination of components to be returned to the core for further service and examination of discharged components in order to detect significant degradation during service. Maintenance programmes should include procedures to prevent the introduction of foreign materials into the reactor. Further guidance on the surveillance and maintenance of items important to safety is given in Ref.[~~5~~9].

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

- Immobility of (single or multiple) control rods due to sticking of metal contacts;
- Significant increase of control rod travel time during a scram event;
- Ageing degradations (e.g. cracks due to embrittlement);
- Mechanical damage;
- Presence of material depositions and/or foreign materials.

7. PREPARATION OF FUEL FOR DISPATCH

7.1. Fuel should be removed from the storage facility only in accordance with an authorization that identifies the fuel type, its position in the facility, its destination and the procedures to be applied during handling.

7.2. The fuel should be selected for loading into a shipping cask that has been approved for use for such fuel (particularly in terms of criticality assessment) on the basis of its burnup, irradiation history and cooling time, so that the radiation levels and decay heat levels remain within the specified limits for the cask. If the cask needs to have special removable neutron absorber curtains or similar devices, procedures should be established to ensure that these are in place before fuel is placed in the ~~container~~ cask. The cask should also be labelled in accordance with the applicable transport regulations and should be clearly marked with radiation symbols and other necessary signs of identification.

7.3. Procedures should be established for the preparation of the shipping cask for transport off the site. These procedures should be followed to ensure, in particular, that the shipping cask is leak tight and has adequate cooling capability, and that the radiation and contamination levels meet the applicable transport requirements. In addition, procedures should be followed to ensure that the equipment necessary for handling the shipping cask is available and has been functionally tested. Procedures should be established with means such as the use of checklists requiring approvals and countersignatures for important hold points to ensure that the fuel contents of the shipping cask have been loaded as specified.

7.4. The transport vehicle should be checked for compliance with transport requirements in respect of levels of external contamination and radiation levels before dispatch from the site.

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

7.6. Before a previously used and supposedly empty cask is opened, it should be ensured that radiation monitors with alarms are 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.

7.7. ~~Detailed~~ Requirements and guidance on the ~~safe~~ transport of radioactive material and the associated safety and environmental aspects can be found in the IAEA Safety ~~Requirements~~ Standards ~~Series publication~~Series publication on ~~Regulations~~ regulations for the ~~Safe~~ safe ~~Transport~~ transport of ~~Radioactive~~ radioactive ~~Material~~ material, see Ref. Regulations for the Safe Transport of Radioactive Material (~~2012~~ 2018 Edition[GS59][CR60]), ~~Specific Safety Requirements,~~ IAEA Safety Standards Series No. SSR-6 (Rev. 1) [~~13~~16~~7~~] and Ref. Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition), ~~Safety Guide,~~ IAEA Safety Standards Series No. SSG-26[GS61][CR62] ~~TS-G-1.1(Rev. 1)~~ [17~~86~~].

8. ADMINISTRATIVE AND ORGANIZATIONAL ASPECTS

8.1. The operating organization is responsible for all aspects of on-site fuel management. Organizational arrangements for core management may vary significantly, depending on the practices and policies of the operating organization. Adequate design support should be provided to the core management groups. The operating organization should ensure that the plant management has been given the required authority and provided with the required support, and that the responsibilities are clearly defined.

8.2. The operating organization's responsibilities in respect of core and fuel management~~ and fuel handling~~ (liaison with other organizations may also be necessary) should include, but are not limited to, the following:

- Arrangements to ensure that a comprehensive core management programme is established and will be maintained at the plant; ~~(see Section 2); provisions~~
- should be made to ensure that the necessary assistance will be provided to the plant management to perform the fuel management tasks described in this Safety Guide;
- Arrangements to ensure that from the design stage onwards the plant management will be provided with the necessary data, design reports and documents relating to manufacturing, construction, commissioning and quality assurance to permit safe plant operation in accordance with the intent and assumptions of the design;
- Periodic surveillance of the fabrication of fuel and core components to ensure that they comply with specifications and applicable requirements ~~for quality~~of the ~~integrated~~ management system (see Ref.[~~3~~4]); arrangements need to be made so that the operating organization has adequate information to perform surveillance of the fabrication;
- Arrangements for ensuring that no modifications to fuel assemblies, core components, handling equipment and/or procedures are carried out without proper consideration and formal approval if so required (see also Ref. Modifications to Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.3 [~~14~~18~~9~~]);
- Arrangements for ensuring that calculational methods are established and kept up to date in order to define fuel cycles and loading patterns for fuel and absorbers to maintain compliance with the applicable operational limits and conditions, to verify operating procedures and establish associated surveillance requirements, and to achieve the optimum utilization of fuel;
- Arrangements for the examination of irradiated fuel for evaluation of its performance;
- Arrangements for transport of fresh and irradiated fuel and core components;
- Arrangements for on-site storage and handling of fresh and irradiated fuel and core components;
- Arrangements for inspection and periodic maintenance of fuel handling equipment;
- Arrangements for ageing management;
- Arrangements for the exclusion of foreign materials, including appropriate provisions to this effect in all relevant procedures;
- Arrangements to ensure that operating personnel are properly qualified and trained;
- The clear definition of responsibilities for all tasks and their assignment to appropriate staff.

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

- Receipt, storage, handling, inspection and disposition of fuel and core components;
- Recording of the location, exposure, physical condition and disposition of fuel and core components;
- Core surveillance to meet the requirements for core management;
- Tests to obtain values for core parameters such as those described in paragraph 2.17 (where appropriate);
- Actions to be taken by plant operators whenever core parameters are outside the specified limits and conditions for normal operation, and corrective actions to be taken to prevent safety limits from being exceeded;
- Independent review of the performance of the core and of proposals for significant modifications to plant items and procedures (see Ref.[~~14~~18~~9~~]);
- Reporting and investigation of unusual occurrences, including root cause analysis.

8.4. Corporate policies should be formulated so as to set and meet the standards expected of the fuel management programme. The senior management should achieve this objective by ensuring the communication of these standards to staff, providing sufficient resources for the specific tasks and monitoring the staff’s performance. The policies should specify the safety objectives and the technical and economic objectives, should establish expected performance levels and should clearly define the responsibilities for achieving these levels. The goals and objectives of activities relating to fuel management should be made achievable by means of appropriate policies and procedures.

8.4.A These policies [CR63]should be based on maintaining the independence between the levels of the defense in depth and an adequate reliability of each level. The influence of human and organizational factors on one, several or all levels of defence in depth should be considered and addressed in all operational activities, to avoid negative impact on the reliability of these levels and the independence between the levels. This principle should be applied to core management.

8.4.B A defence in depth approach [CR64]should be generally applied to safety related activities in plant operations, including core management and fuel handling. These activities should be carefully planned, appropriately authorized and carried out in accordance with properly approved procedures by competent staff, implementing management system practices to achieve a high level of safety performance. In addition, adequate independent safety assessments and verifications should be carried out for different operational activities, to ensure their reliable accomplishment.

8.5. Organizational interfaces should be specified, established and documented by the operating organization Ref.[2]. The documentation should specify what information is needed, the persons responsible for supplying it and the reviews, comments and approvals that are necessary. When the operating organization arranges to obtain core management services from other groups within the operating organization itself or from other organizations, these services should be readily accessible. ~~Guidance in respect of administrative controls is provided in IAEA safety standards on quality assurance [3].~~

8.6. The operating organization should fully consider the tasks to be performed for core management and fuel handling and should provide sufficient staff to perform them. The number of staff necessary will depend, for example, on:

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

8.7. The operating organization should identify the key competences necessary for the tasks, such as competence in criticality assessment and transient analysis and expertise with tools for carrying out core calculations. It should consider whether these competences should be provided from within the operating organization as a site based or a corporate function, or as a contracted task. Whichever option is chosen, the operating organization should ensure that the necessary competence is established and maintained to meet the required level of safety. If tasks are to be contracted out, the operating organization should have sufficient knowledge of the work done on its behalf to judge its technical validity and should know where to seek advice and assistance if necessary.

8.8. A quality assurance system for the fuel management programme on the site should be extended to include suppliers. The operating organization should ensure that the manufacturers and designers have acceptable quality assurance programmes. It should also ensure that the manufacturers and designers comply with the quality assurance programmes, for example, by performing periodic audits.

8.9. Lessons learned from experience can be applied to enhance safe operation. Safety relevant information obtained from operating experience relating to fuel should be recorded and should be exchanged with the vendor, with other plants of the same operating organization, with licensing organizations (if applicable) and with other organizations, particularly those that operate similar reactors.

9. DOCUMENTATION

9.1. For the safe operation of a nuclear power plant, the operating organization should have adequate information on the fuel, core parameters and components, and on the handling equipment for the fuel and for components. This information should include details of the design and installation and the results of safety analyses. The information obtained during commissioning and subsequent operation should be evaluated and retained as it becomes available.

~~9.1.~~9.2. This baseline information should be augmented during subsequent plant operation by a comprehensive record system covering core management and handling activities for fuel and core components. This record system should be designed to provide sufficient information for the correct handling of fuel and core components on the site, and for detailed analysis of the performance of the fuel and of activities relating to core safety throughout the operating life of the plant. Guidance for record keeping can be found in Ref.[~~3~~4].

~~9.2.~~9.3. Typical records important to core management and handling of fuel and core components should include, but are not limited to, the following, as appropriate:

- The design basis, material properties and dimensions of the core;
- Plant operational records;
- Data relating to installation tests and commissioning tests and records of special operating tests;
- Core operating history (typically, hourly logs of parameters such as temperature and flow rate from the plant computer);
- Power, energy and heat balance;
- Reactivity balance and critical configuration during startup;
- In-core flux measurements;
- Refuelling programmes and supporting information;
- Refuelling patterns and schedules;
- Location of each fuel assembly throughout its time on-site;
- History of burnup for each individual fuel assembly;
- Data on fuel failures;
- Results of examinations of fuel and components;
- Status, repair history, modifications and test results for handling equipment for fuel and components;
- Coolant and moderator inventories, chemical quality and impurities;
- Records relating to core management (calculational notebooks and computer code descriptions);
- Computer calculations of core parameters, power and neutron flux distributions, isotopic changes and additional data considered important to fuel

performance;

- Operational data to validate methods, to provide input for the refuelling plan and to form the basis for the evaluation of operational safety;
- Comparisons of test results and validation of computational methods.

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~~GLOSSARY~~

~~**burnable absorber.** Neutron absorbing material, used to control reactivity, with particular capability of being depleted by neutron absorption.~~

~~**cladding (material).** An external layer of material applied directly to nuclear fuel or other material to provide protection from a chemically reactive environment and containment of radioactive products produced during the irradiation of the composite. It may also provide structural support.~~[5]

~~**core components.** The elements of a reactor core, other than fuel assemblies, that are used to provide structural support of the core construction, or the tools, devices or other items that are inserted into the reactor core for core monitoring, flow control or other technological purposes and are treated as core elements.~~[6]

~~**fresh fuel.** In this document, the term ‘fresh fuel’ means new fuel or unirradiated fuel; even though the fuel may have been fabricated from fissionable materials recovered by reprocessing previously irradiated fuel.~~

~~**fuel assembly.** A set of fuel elements and associated components which are loaded into and subsequently removed from a reactor core as a single unit.~~

~~**fuel element (fuel rod for light water reactors).** A rod of nuclear fuel, its cladding and any associated components necessary to form a structural entity.~~

~~**operational limits and conditions.** A set of rules setting forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the regulatory body for safe operation of an authorized facility.~~

~~**storage.** The holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the intention of retrieval.~~

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[5] ~~In the context of this Safety Guide, the cladding consists of a tube which surrounds the fuel and which, together with the end cups or plugs, also provides structural support.~~

[6] ~~Examples of core components are reactivity control devices or shutdown devices, neutron sources, dummy fuel, fuel channels, instrumentation, flow restrictors, burnable absorbers and samples of reactor vessel material.~~

~~**dry storage.** Storage facilities that store the fresh or spent fuel in a gas environment such as air or an inert gas. Dry storage facilities include facilities for the storage of spent fuel in casks, silos or vaults.~~

~~**wet storage.** Storage facilities that store spent fuel in water or other liquid. The universal mode of wet storage consists of storing spent fuel assemblies or elements in water or other liquid pools, usually supported on racks or in baskets, and/or in canisters that also contain liquid. The pool liquid surrounding the fuel provides for heat dissipation and radiation shielding, and the racks or other devices ensure a geometrical configuration that maintains subcriticality.~~

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