GOVERNMENT OF INDIA

AERB SAFETY GUIDE

CORE MANAGEMENT AND FUEL HANDLING IN OPERATION OF BOILING WATER REACTORS

ATOMIC ENERGY REGULATORY BOARD

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CORE MANAGEMENT AND FUEL HANDLING IN OPERATION OF BOILING WATER REACTOR

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Atomic Energy Regulatory Board
Mumbai 400 094

FOREWORD

Safety of public, occupational workers and protection of environment should be assured while activities for economic and social progress are pursued. These activities include the establishment and utilisation of nuclear facilities and use of radioactive sources. They have to be carried out in accordance with relevant provisions in the Atomic Energy Act 1962 (33 of 1962).

Assuring high safety standard has been of prime importance since the inception of nuclear power programme in the country. Recognising this aspect, the Government of India constituted the Atomic Energy Regulatory Board (AERB) in November 1983 vide Standing Order No. 4772 notified in the Gazette of India dated 31.12.1983. The Board has been entrusted with the responsibility of laying down safety standards and to frame rules and regulations in respect of regulatory and safety functions envisaged under the Atomic Energy Act 1962. Under its programme of developing safety codes and guides, AERB has issued four codes of practice covering the following topics:

Safety in Nuclear Power Plant Siting

Safety in Nuclear Power Plant Design

Safety in Nuclear Power Plant Operation

Quality Assurance for Safety in Nuclear Power Plants

Safety guides are issued to describe and make available methods of implementing specific parts of relevant codes of practice as acceptable to AERB. Methods and solutions other than those set out in the guides may be acceptable if they provide at least comparable assurance that nuclear power plants can be operated without undue risk to the health and safety of general public and plant personnel.

The codes and safety guides may be revised as and when necessary in the light of experience as well as relevant development in the field. The annexures, foot-notes, list of participants and bibliography are included to provide information that might be helpful to the user.

The emphasis in the codes and guides is on protection of site personnel and public from undue radiological hazard. However, for other aspects not covered in the codes and guides, applicable and acceptable national and international codes and standards shall be followed. Industrial safety shal1 be assured through good engineering practices and through compliance with the Factories Act 1948 as amended in 1987 and the Atomic Energy (Factories) Rules, 1996.

Thc Code of Practice on Safety in Nuclear Power Plant Operation states the minimum requirements to be met during operation of a land based thermal neutron reactor power plant in India for assuring safety. This Safety Guide provides guidance for Core Management and Fuel Handling in Operation of Boiling Water reactors in India. While elaborating the requirements stated in the Code of Practice on Safety in Nuclear Power Plant Operation, it provides necessary information to assist Operating Organisation in the management of Boiling Water Reactors for safe operation.

This Safety Guide has been prepared by the staff of AERB and other professionals. In drafting this guide, they have used extensively the relevant International Atomic Energy Agency (IAEA) documents under NUSS programme, especially the IAEA Safety Guide on "Safety Aspects of Core Management and Fuel Handling for Nuclear Power Plants" (50-SG-O10).

Experts have reviewed the guide and the AERB Advisory Committees have vetted it, before issue. AERB wishes to thank all individuals and organisations who reviewed the draft and finalised this safety guide. The list of persons who have participated in the committee meetings, along with their affiliations, is included for information.

(P. Rama Rao)
Chairman, AERB

DEFINITIONS

Acceptable Limits

Limits acceptable to the Regulatory Body.

Accident Conditions[1]

Substantial deviations from Operational States which could lead to release of unacceptable quantities of radioactive materials. They are more severe than Anticipated Operational Occurrences and include Design Basis Accidents and severe accidents.

Anticipated Operational Occurrences [2]

All operational processes deviating from normal operation during the operating life of the plant and which in view of appropriate design provisions, neither cause any significant damage to Items Important to Safety nor lead to Accident Conditions (see Operational States).

Approval

A formal consent issued by the Regulatory Body to a proposal.

Atomic Energy Regulatory Board (AERB)

An authority designated by the Government of India to enforce the rules promulgated under the relevant sections of the Atomic Energy Act, 1962, for the control of radioactive substances (section 16), special provisions to safety (section 17) and administration of the Factories Act, 1948 (section 23).

Cladding[3]

An external sheath of material over nuclear fuel or other material that provides protection from a chemically reactive environment and containment of radioactive products produced during irradiation of the composite. It also provides a structural support.

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1 A substantial deviation may be a major fuel failure, a Loss of Coolant Accident (LOCA) etc. Examples of engineered safety features are: an Emergency Core Cooling System (ECCS) and containment.

2 Examples of Anticipated Operational Occurrences are loss of normal electric power and faults such as turbine trip, malfunction of individual items of normally running plant, failure to function of individual items of control equipment, and loss of power to main coolant pump.

3 In the context of this guide, cladding consists of a tube which surrounds the fuel and which, together with the end cups or plugs, also provides a structural support.

Commissioning[4]

The process during which structures, systems and components of a facility, having been constructed, are made operational and verified to be in accordance with design specifications and to have met the performance criteria.

Core Components

All items other than fuel, which reside in the core of a Nuclear Power Plant (NPP) and have a bearing on fuel integrity and utilisation. (e.g., reactor vessel, control rods, fuel bundles, coolant etc.)

Core Management

All activities associated with use of fuel and core components in an NPP with the ultimate aim of ensuring integrity and efficient use of the same.

Cycle

The period between the time when the reactor operation is resumed after refuelling (to attain the desired excess reactivity) to the time when the reactor is shut down for refuelling.

Documentation[5]

Recorded or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results.

Emergency Situation

A situation which endangers or is likely to endanger the safety of NPP, site personnel or the environment and the public.

Examination

An element of inspection consisting of investigation of materials, components, supplies, or services, to determine conformance with those specified requirements that can be determined by such investigation.

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[4] Thc terms Siting, Construction, Commissioning, Operation and Decommissioning are used to delineate the five major stages of the authorisation process. Several of the stages may coexist; for example Construction and Commissioning, or Commissioning and Operation.

[5] The definitions refer to Quality Assurance Activity as discussed in Quality Assurance code and guides. Prior specifications means approved specification.

Fuel Bundle (also called Fuel Assembly)

An assembly of fuel elements identified as single unit.

Fuel Element (Fuel Pin/Fuel Rod)

A component (rod, pin, cylinder, etc.) that consists primarily of the nuclear fuel and its encapsulating materials.

Fuel Handling

All activities relating to receipt, inspection, storage and loading of unirradiated fuel into the core; unloading of irradiated fuel from the core, its transfer, inspection, storage and despatch from the NPP.

Inspection

Quality Control actions which, by examination, observation or measurement determine the conformance of materials, parts, components, systems, structures as well as processes and procedures, with predetermined quality requirements.

Item

A general term covering structures, systems, components, parts or materials.

Items Important to Safety

The items which comprise:

(1) those structures, systems, and components whose malfunction or failure could lead to undue radiological consequences at plant or outside the plant;[6]

(2) those structures, systems and components which prevent Anticipated Operational Occurrences from leading to Accident Conditions; and,

(3) those features that are provided to mitigate the consequences of malfunction or failure of structures, systems or components.

Non-Conformance

A deficiency in characteristics, documentation or procedure which renders the quality of an item unacceptable or indeterminate.

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[6] This includes successive barriers set up against the releases of radioactivity from nuclear facilities.

Normal Operation

Operation of a plant or equipment within specified Operational Limits and Conditions. In the case of a nuclear power plant, this includes start-up, power operation, shutting down, shutdown states, maintenance, testing and refuelling (see Operational States).

Nuclear Power Plant (NPP)

A thermal neutron reactor or reactors together with all structures, systems and components necessary for safety and for the production of power, i.e. electricity.

Nuclear Safety

Protection of all persons from undue radiological hazard.

Operation 4

All activities following commissioning and before decommissioning performed to achieve in a safe manner, the purpose for which the installation was constructed, including maintenance.

Operation Code

Code of Practice on Safety in Nuclear Power Plant Operation, AERB/SC/O, 1989 issued by AERB.

Operational Limits and Conditions (OLCs)

Limits on plant parameters and set of rules on the functional capability and the performance level of equipment and personnel, approved by the Regulatory Body, for safe operation of the facility.

Operating Organization[7]

The organization so designated by the Responsible Organisation and authorised by the Regulatory Body to operate the plant.

Operating Personnel

Those members of Site Personnel who are involved in the operation of NPP.

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[7] In the present context the Directorate of Operations, NPCIL is the Operating Organization.

Operational Records

Documents, such as instrument charts, certificates, log books, computer print-outs and magnetic tapes, made to keep an objective history of the NPP operation.

Operational States

The states defined under Normal Operation and Anticipated Operational Occurrences.

Plant Management

The members of site personnel who have been officially delegated responsibility and authority by the operating organization for directing the operation of the plant.

Poison (nuclear poison)

A substance having high neutron-capture cross-section reducing reactivity.

Prescribed Limits

Limits established or accepted by the Regulatory Body for specific activities or circumstances that must not be exceeded.

Protection System

A part of Safety Critical System which encompasses all those electrical, mechanical devices and circuitry, from and including the sensors up to the input terminals of the safety actuation system and the safety system support features, involved in generating the signals associated with safety tasks.

Quality 5

The totality of features and characteristics of a product or service that bear on its ability to satisfy a defined requirement.

Quality Assurance (QA) 5

Planned and systematic actions necessary to provide adequate confidence that an item or facility will perform satisfactorily in service as per design specifications.

Quality Control 5

Quality Assurance action, which provides a means to control and measure the characteristics of an item, process or facility in accordance with established requirements.

Reactivity

A parameter, giving the deviation from the criticality of a nuclear chain reacting medium.

$$p = (k_{eff} - 1) / k_{eff}$$

where k_{eff} is the effective multiplication factor. Reactivity, p, is expressed in terms of mk, milli-k (10^{-3}k).

Other units used are dollar, cent, inhour and pcm.

Records

Documents that furnish an objective evidence of the quality of items or activities affecting quality. It also includes logging of events and other measurements.

Responsible Organization (RO)[8]

The organisation having an overall responsibility for siting, design, construction, commissioning, operation and decommissioning of a facility.

Safety

(See nuclear safety).

Safety Limits

Limits upon process variables within which the operation of the facility has been shown to be safe.

Safety Systems

Systems important to Safety, provided to assure, under Anticipated Operational Occurrences and Accident Conditions, the safe shutdown of the reactor (Shutdown System), the heat removal from the core (Emergency Core Cooling System) and containment of any released radioactivity (Containment Isolation System).

Services

The performance by a supplier of activities such as design, fabrication, installation, inspection, non-destructive examination, repair and/or maintenance.

[8] In the present context, the Nuclear Power Corporation of India Limited (NPCIL) is the Responsible Organisation for nuclear power plants in India.

Site

The area containing the facility, defined by a boundary and under the effective control of the Plant Management.

Site Personnel

All persons working on the site, either permanently or temporarily.

Shutdown Margin

The minimum specified subcriticality of reactor under shutdown condition at any time during operation from the most reactive state of the core or under postulated failure of a specified number of shutdown devices of the highest reactivity worth (s) for the given shutdown system.

Surveillance[9]

The act of monitoring or observing to verify whether an item or activity conforms to specified requirements.

Technical Specification for Operation

A document submitted on behalf of or by the responsible organisation covering operational limits and conditions, surveillance and, administrative control requirements for the safe operation of the facility and approved by the Regulatory Body.

Testing

The determination or verification of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental or operational conditions.

Verification

The act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services or documents conform to specified requirements.

[9] This includes activities performed to assure that provisions rnade in the design for the safe operation of NPP continue to exist during the life of the plant.

CONTENTS

1. INTRODUCTION

1.1 General

1.1.1 This Safety Guide has been prepared as part of the Atomic Energy Regulatory Board's (AERB) programme for establishing codes of practice and safety guides relating to nuclear power plants (NPPs). It supplements the Code of Practice on Safety in NPP Operation (AERB/SC/O). The provisional list of safety guides on operation is given at the end of this publication.

1.1.2 This Safety Guide deals with core management and fuel handling aspects in operation of boiling water reactors (BWRs).

1.1.3 Core management, from an operational point of view, essentially comprises all activities associated with the use of fuel and core components in an NPP with the ultimate aim of ensuring integrity and efficient use of fuel, core components and core materials. Reactor vessel, control rods, fuel bundles and light water coolant/moderator are the major components of the reactor core.

1.1.4 The safety requirements to be met, to maintain the integrity of the core, and its components are included in the Safety Guide on Operational Limits and Conditions, (AERB/SG/0-3).

1.1.5 The term 'fuel handling' in this Safety Guide includes in-core and out-of-core movement of fresh and irradiated fuel, its storage, preparation for despatch and on-site fuel transportation.

1.1.6 The Responsible Organisation (RO) shall ensure that satisfactory administrative arrangements are made for core management activities and that close liaison amongst the design and operating groups is established and maintained, considering the restraints imposed by the fuel and plant design limitations as well as the dynamic core conditions during operation.

1.1.7 Plant Management shall ensure that satisfactory administrative controls are established among the operating, technical and maintenance groups of the plant such that requirements specified in the Code are adhered to following the guidelines from this Guide.

1.2 Objectives

1.2.1 The main objectives of this Safety Guide are as follows:

(i) To highlight the purpose and content of operating procedures to predict, monitor, control and to maintain the specified core conditions and parameters to ensure the integrity of the fuel and core components during start-up, power operation, shutdown and refuelling. The focus is on the management of reactivity and power distribution in the core such that under no circumstances an uncontrolled increase in power occurs and that a specified shutdown margin and hence safe shutdown capability is always maintained;

(ii) To describe the important considerations in establishing fuelling plans and programmes for efficient use of fuel to obtain optimum fuel burnup and core performance subject to maintaining the integrity of the fuel bundle so as to minimise contamination of the coolant system by radioactive fission products;

(iii) To emphasise the necessity for establishing procedures to prevent and control the failure of fuel bundles in the core during normal operation and to take prompt remedial action such as reduction of power and coolant purification as necessary.

(iv) To give guidelines in handling fresh fuel such that the fuel bundle is tested to be according to design specification and that its integrity is not violated before its entry into the core;

(v) To bring out necessary guidelines for safe handling and management of the irradiated bundles and core components following their discharge from the core, their storage in spent fuel bay and their transport from the site.

(vi) To highlight proper co-ordination necessary between the Responsible Organisation, Plant Management and other agencies in order to achieve efficient, safe core management and fuel handling.

1.3 Scope

1.3.1 This Safety Guide describes the safety objectives of core management, the tasks to be accomplished to meet these objectives and the activities undertaken to perform these tasks. It covers the storage and handling of fuel and core components, their loading and handling as well as insertion and removal of core materials such as moderator/coolant, control blades, fuel channel, etc. However, this Guide does not cover accident/post-accident scenarios arising out of either loss of coolant or loss of control.

1.3.2 It also covers situations arising out of core configuration involving fuels and core components other than the ones for which the core was originally designed and approved for operation and transition to the new fuel configurations such as low enriched uranium to mixed oxide (MOX) fuel. The use of MOX fuel will require special measures for reactivity control in operating and accident conditions.

1.3.3 It includes guidelines on administrative and organisational aspects, maintenance of records and conducting inspection and surveillance related to core management.

1.3.4 The loading of transport container with irradiated fuel and the preparation for transport off-site are also covered in this Safety Guide.

1.3.5 The versions of boiling water reactors have changed over a period of time, with each later version showing improvements in terms of fuel design, engineering developments and thermodynamics. Different versions of BWRs are described in Annexure-IV. As far as core management and fuel handling aspects of the different versions are concerned, various aspects covered in this guide could be applied without any significant change.

2. CORE MANAGEMENT

2.1 Safety Objectives and Tasks of Core Management

2.1.1 Safety Objectives

The core management shall be such as to ensure safety of the reactor fuel and core components in all operational states with a required safety margin. Efficient and safe use of reactor fuel in the reactor requires specified performance levels of the associated systems for keeping the core parameters within specified values.

2.1.2 Core Management Tasks

The basic core management tasks to be undertaken to ensure safety of the core and its components are as follows:

(i) Maintenance of core conditions and parameters important to safety, within specified limits by timely assessment, verification, monitoring and control, specially in relation to nuclear and thermal effects;

(ii) Identifying and removing failed fuel at the end of the cycle,

(iii) Preparing and implementing refuelling plan, to achieve efficient utilisation of fuel and optimum core performance while ensuring the integrity of the fuel.

2.1.3 Core Conditions and Parameters Important to Safety

Core conditions and parameters that are important for the basic tasks to ensure safety of the reactor core include:

(i) Conformance of fresh fuel to design specifications;

(ii) Fuel loading patterns;

(iii) Shutdown margin;

(iv) Heat transfer and recirculation flow;

(v) Reactivity addition and removal rates;

(vi) Coefficients of reactivity (temperature, void and pressure);

(vii) Characteristics of the control systems;

(viii) Neutron kinetic parameters;

(ix) Neutron flux and power distribution;

(x) Heat dissipation from the irradiated fuel to the ultimate heat sink in all operational states and accident conditions;

(xi) Reactor water chemistry; and

(xii) Fission product activity in the reactor water and the off-gas.

2.1.4 Miscellaneous

To ensure the safe use of fuel in the core, the core management should include:

(i) Assessment of safety implications of any component or material proposed to be inserted into the reactor vessel;

(ii) Investigations into causes of fuel failures and methods to avoid such failures;

(iii) Assessment of irradiation effects on core components and core materials.

2.2 Core Management Activities

2.2.1 General

The RO shall organise to implement the following activities to facilitate the basic tasks of subsection 2.1.2:

(i) Collection and updating of baseline information on nuclear fuel and core components;

(ii) Establishment of core monitoring and testing programmes (commissioning tests, etc.);

(iii) Prediction of core conditions and validation of predictions;

(iv) Establishment and implementation of fuelling programmes (Annexure-III);

(v) Establishment of monitoring programmes and criteria for assessment of failed fuel; and

(vi) Inclusion of safety requirements in operating procedures and verification of compliance.

The above tasks have to be carried out throughout the operational life of the reactor. Since the core conditions change with time and power output, accomplishment of the above tasks requires a continuous knowledge of reactor core conditions and the availability of applicable operational limits and conditions, modified as necessary from time to time, to ensure safe and efficient operation.

2.2.2 Collection and Updating of Baseline Information

Safe operation of NPP requires Plant Management to be in possession of adequate information on the fuel and fuel handling equipment, core parameters, status of core components and component handling equipment and they should be retrievable. Such information shall include design and safety analysis information as well as information obtained during commissioning, subsequent operation and maintenance.

This information should be in the nature of in-situ measurements and, where not practicable, must be based on validated estimates.

2.2.2.1 The design and safety analysis information shall include:

(i) Basic design information and specifications of the plant, 'as-built' installation drawings etc.;

(ii) Criteria for detailed design of fuel, core components, core flow distribution including material properties and effect of irradiation;

(iii) Initial fuel loading pattern and criteria for subsequent re-loads;

(iv) Results of thermal hydraulic analyses and related limits including thermal margin during steady-state operation, anticipated transients and design basis accident conditions;

(v) Calculation of the following parameters for the initial core and subsequent reloaded cores:

(a) shutdown margin under all operational states an accident conditions, demonstration of shutdown margin at most reactive state,

(b) location and reactivity worth of the most effective control rod or rod groups,

(c) reactivity coefficients of temperature, power, pressure and void over the operating range and for anticipated operational occurrences,

(d) power distribution in the core and within the fuel bundles at various reactor powers and the corresponding control rod patterns, and

(e) predicted critical control rod pattern at reactor start-up,

(vi) Location, sensitivities, ranges and overlapping of different neutron instrumentation;

(vii) Heat generation in fuel, coolant and other core components;

(viii) Assessment of irradiation effects on core components and the reactor vessel;

(ix) Assessment of irradiation-induced reactivity changes in control rods and gensitivity changes in the in-core instrumentation;

(x) Assessment of reactor dynamics (instability due to xenon, reactivity feedback instability, rates of negative reactivity insertion in different core conditions).

2.2.2.2 The baseline operating data collected during commissioning and operation shall include, as applicable:

(i) Measured parameters for comparison with design estimates, such as core reactivity, neutron flux and flux distribution as mentioned in subsection 2.2.2.1;

(ii) Assessment of absorption characteristics of control rod system;

(iii) Calibration data for neutron flux instrumentation and other core instrumentation considering change in sensitivity caused by neutron fluence over a period of time;

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(iv) Fuel loading plan giving type, serial number, and location in core of fuel assemblies;

(v) Heat balance;

(vi) Control rods scram timings, poison injection time, control rod friction test timings, timings between fully IN to fully OUT for individual control rods;

(vii) Radiation levels at specified locations; and

(viii) Fission product activity in reactor water and off-gas.

2.2.2.3 The commissioning programme (pre-operational tests, fuel loading, initial criticality and low and high power tests) shall ensure that all baseline operating data are collected. Suitable tests shall determine parameters such as actuation times of control rods, absorber reactivity worth, flux measurement and power measurement. The Safety Guide on Commissioning of Nuclear Power Plants, (AERB/SG/0-4) provides guideline on tests which shall be considered for this stage in the programme.

2.2.2.4 The baseline data referred to in sub-section 2.2.2:2 shall be compared, to the extent practicable, with design predictions. Significant discrepancies between design and measured values with regard to any parameter shall be investigated to evaluate the safety implications and establish the cause for the discrepancies. Corrective action, including possible modifications of the methods of design calculation or measurement, shall be taken as dictated by conclusions of such an investigation.

2.2.2.5 Experience from similar reactors as may be applicable may be used throughout the implementation of the commissioning programme and during the operational phase of the reactor.

2.2.3 Core Monitoring

2.2.3.1 During reactor start-up, power operation, shutdown, testing, and refuelling, core parameters shall be monitored to determine whether core conditions conform to operational limits and conditions (AERB/SG/0-3) and, if they do not conform, appropriate action shall be initiated to maintain the reactor in safe condition. The results of core monitoring during testing and operation shall also be applied to the review for optimisation of core performance.

Parameters to be monitored continuously or at appropriate time intervals in relevant phases (start-up, power operation etc.) include, as applicable:

(i) Neutron/Heat flux, profiles for axial and radial distribution based on in-core detectors;

(ii) Rate of change of neutron flux during start-up;

(iii) Positions of control rods, water level in the reactor vessel, reactor pressure and reactor water temperature;

(iv) Operability of reactivity control rods;

(v) Hot scram testing of selected drives;

(vi) Recirculation flow, feedwater inlet temperature;

(vii) Thermal power output from the core;

(viii) Minimum critical power ratio or critical heat flux ratio or departure from nucleate boiling ratio, maximum linear heat rate;

(ix) Fission product activity in reactor water and off-gas;

(x) Clean-up flow for reactor water; and

(xi) Chemical parameters of the reactor water such as pH, conductivity, amount of crud and the concentration of impurities and products of radiolytic decomposition

2.2.3.2 The instrumentation for monitoring the relevant parameters is normally arranged to:

(i) Have adequate range overlap at all power levels from the source range to full power;

(ii) Have suitable sensitivity and range for all operational states and, where appropriate, accident conditions; and

(iii) Facilitate the evaluation of core performance and assessment of abnormal situations by operators.

2.2.3.3 Parameters such as reactor water temperature, reactor pressure, reactor water level, recirculation flow and neutron flux expressed in terms of core power should be measured and displayed to the operator In addition, where applicable, changes in core parameters due to fuel burn-up may require changes in alarm levels and in safety system settings to be specified. To ensure this aspect, instrument-operator interface is required.

For operation at reduced power or in the shutdown state, consideration shall be given to the need to adjust the set points for alarm annunciation or safety action initiation to maintain the appropriate safety margins.

2.2.3.4 In many cases the parameters important to safety that affect fuel behaviour are not directly measurable. In such cases they are derived by analysis from measured parameters, the loading pattern of the fuel, and the distribution of the components in the reactor core which influence neutron flux distribution or heat transfer. These derived values are used as basic input for establishing operating limits and conditions, but the values of parameters specified for use by the operator should be given in terms of instrument indications.

2.2.3.5 The parameter values such as those related to chemical control are derived from direct measurements or from periodic analyses of reactor water samples. The operating personnel shall be informed of the results of these analyses. To avoid specified values of such parameters being exceeded, the operating personnel shall be provided with instructions concerning the proper action to be taken, should these parameters tend to approach pre-established limits.

2.2.4 Prediction of Core Conditions

2.2.4.1 As a consequence of fuel burn-up, the neutron production and capture changes in both space and time. This necessitates changes in control rod pattern, with consequent effects on power distribution, peak fuel power and criticality configuration and conditions at start-up. These changes and the consequent effects shall be predicted for both steady-state and transient conditions. The results of such predictions should be compared with measured parameters as far as practicable. In the event of significant discrepancies, appropriate action shall be taken to put the reactor into a safe shutdown condition and investigations to determine the cause of the discrepancy carried out. The predictions required for core management include, as applicable:

(i) Variations in reactivity with irradiation of the fuel;

(ii) Expected control rod pattern for criticality and the recommended steps needed to approach and achieve criticality and intended power escalation. Typical examples of control rod notch worths near criticality should be examined;

(iii) Changes resulting from operation in parameters relating to core conditions of subparagraphs 2.2.2.1 (iv), (v), (vii) and (x);

(iv) Measures needed to maintain core reactivity at the desired power by, for example, changes in control rod positions, reactor water temperature, void content, xenon concentration etc.. Such measures should be analysed to ascertain that they do not adversely affect flux and power distribution in the fuel assemblies or elsewhere in the core;

(v) Reduction in control effectiveness and structural degradation of control rods due to irradiation effects, including gas pressure build-up;

(vi) Effects of irradiation on neutron flux detectors, particularly reduction in sensitivity and change in material properties; and

(vii) Adequacy of neutron source strength and sensitivity for startup, particularly after a long shutdown. In general, regenerative neutron sources are used, for example, antimony-beryllium sources whose half-life is around two months. Source strength will reduce during long shutdowns and to meet the requirement of minimum source counts, replacement of sources may be needed.

2.2.4.2 Methods shall be established to correlate relevant measured parameters with other parameters important to safety, such as fuel or component temperatures, critical heat flux ratio, and peaking factors which are not directly measured. The correlations shall be in the form of a written document and shall form the basis for appropriate action to ensure conformity with operational limits and conditions relating to fuel or component temperature, chemical reactivity control, reactor power etc..

2.2.4.3 The measured or derived parameters to be compared with predictions include, as applicable:

(i) Power generation in the core and its distribution;

(ii) Neutron flux;

(iii) Control rod position;

(iv) Core flow and bypass flow;

(v) Core pressure and pressure drop; and

(vi) Fission product activity in the reactor water.

2.2.5 Establishment and Implementation of Fuelling Programmes

The initial fuel loading pattern includes configuration of control rods, burnable absorbers, target power shape, flux shaping absorbers and other core components to be inserted or removed. For subsequent refuelling schedules, fuel shuffling is also included in the fuelling programme.

2.2.5.1 While achieving the rated power and target fuel burn-up, and providing sufficient reactivity to compensate for fuel depletion and fission product build-up, the safety objectives of fuelling programme shall be met in all cycles of operation throughout the reactor life starting from initial fuel loading. These safety objectives include:

(i) Maintaining neutron/heat flux distribution and other core parameters within applicable operational limits and conditions; and

(ii) Meeting shutdown margin requirements.

2.2.5.2 The fuelling programme would include the reload pattern, the fuel to be shuffled, control blades and in-core instruments to be shuffled. It also should include the assurance that the safety objectives of the fuelling program can be met over the entire cycle and also the subsequent cycles.

2.2.5.3 Aspects that shall be considered in the establishment and implementation of a fuelling programme include,-as applicable:

(i) Fuel burn-up and consequent structural and metallurgical limitations;

(ii) Core flow and bypass flow;

(iii) Mechanical capability of fuel bundles to withstand reactor core conditions for reshuffling and re-using of irradiated fuel bundles;

(iv) Positioning of unirradiated and irradiated fuel in the core with due consideration of their orientation, enrichments and poison levels;

(v) Depletion of neutron absorber in control rods and of burnable poisons;

(vi) The possibility that one control rod (usually the one with the highest reactivity worth) remains inoperable in the fully or partly withdrawn or inserted position; and

(vii) Deviations of actual core operating parameters from values used in the fuelling programme; these require consideration of control rod and absorber configurations, fuel burn-up, flux distribution and depletion of neutron absorbers and burnable poisons.

2.2.5.4 The core conditions shall be assessed before the resumption of operation after refuelling to verify that all applicable operating limits and conditions are met throughout the following reload cycle. The assessment should be based on core conditions at the end of the previous cycle and on the completion of the fuelling based on the new fuel pattern. In particular, the calculated core parameters should be such as to ensure that the reactor can be shut-down with a predetermined margin throughout the new reload cycle, and suitable tests shall be carried out to confirm this shutdown capability, assuring that thermal limits can be satisfied throughout the cycle. As a result of the new pattern, more restrictive limits may be necessary, for the whole or for a part of the new reload cycle.

2.2.5.5 The core predictions required to be made for assessments mentioned in sub-section 2.2.5.3 above are given in sub-section 2.2.4. During a period of core operation, simulations using data pertaining to actual reactor operations or control rod movements may be used as a basis for assessing core performance. In addition, other data such as fuel burn-up, reactivity, power density and neutron flux distribution may be obtained in these simulations.

2.2.5.6 The fuelling programme shall specify the control rod patterns and sequencing which satisfy control rod worth and power distribution requirements. Inspection and tests shall be performed after a reload pattern to ensure that the core was correctly constituted and to verify core characteristics.

Recommended tests include: a check of core power symmetry by checking for mismatches between symmetric detectors, withdrawal and insertion of each control rod to check for operability, a demonstration that the strongest worth control rod in the fully withdrawn condition meets the cold shutdown margin as specified in technical specification document, and comparison of predicted and measured critical rod configurations for non-voided conditions in accordance with planned rod withdrawal sequences.

2.2.5.7 Control rod withdrawal sequences are developed in an uniform, symmetric and dispersed way to ensure low rod worths and low notch worths during withdrawal. There is a likelihood that an operator may select an out-of-sequence rod, which results in higher worth. To avoid such possibility, Rod Worth Minimiser (RWM) is an engineered safety feature to monitor control rod movement by the operator and assure adherence to the specified control rod withdrawal sequence.

RWM is a back-up to procedural control to limit control rod worths so that in the event of control rod drop accident, which is a design basis accident, reactivity addition rate would not lead to significant damage to fuel nor to the primary coolant system.

2.2.6 Failed Fuel

2.2.6.1 Fuel failure is indicated by increase in fission product activity above the normal value in the reactor water and off-gas. Fission product activity monitoring shall therefore be carried out routinely at a predetermined frequency by means of an on-line instrument or by measurements of the activity in samples or by both techniques.

2.2.6.2 The normal value of fission product activity in the reactor water shall be determined during the initial period of reactor operation to provide a reference level.

2.2.6.3 Operation at power may be continued even when the existence of failed fuel is indicated by small increases of the fission product activity in the coolant. The criteria for shutting down to remove failed fuel are generally expressed as limits either on the maximum reactor water activity, permissible off-gas activity in order to minimise actual or potential exposure of site personnel and public. The fuelling plan shall consider the identification of failed fuel by in-core/out-of-core sipping tests in shutdown condition.

2.2.7 Safety Requirements to be Included in Operating Procedures

2.2.7.1 Operating procedures on reactor start-up, power operation, shutdown and refuelling need to include constraints necessary for maintenance of fuel integrity and compliance with operational limits and conditions throughout the life of the fuel.

Core management safety requirements to be incorporated in operating procedures include:

(i) Identification of the instruments to be used by the operator to monitor the reactor so that relevant reactor parameters can be maintained within the range consistent with design intent and assumptions, and in accordance with operational limits and conditions;

ii) Alarm settings and safety settings to limit parameters having a bearing on fuel and clad temperatures, taking into account changes in core conditions due to fuel bum-up or fuelling;

(iii) Parameters to be recorded for comparison with predictions of core conditions;

(iv) Limits of discrepancy between predicted and actual criticality conditions and action to be taken when limits are reached;

(v) Limits for chemical parameters (see subparagraph 2.2.3.1(xi) of reactor water;

(vi) Limits on the rate of rise of power;

(vii) Limits on flux peaks;

(ix) Control rod patterns and sequencing;

(x) Action to be taken for inoperable or other abnormal condition of control rods;

(xi) Criteria for determining fuel failure and the actions to be taken when failure is indicated; and

(xii) Identification and replacement of faulty in-core neutron flux detectors.

2.3 Core Management Activities for Configurations with New Types of Fuel and Core Components.

2.3.1 General

In the event of introduction of new types of fuel or core components, some additional special core management activities become necessary. A few cases may also call for repetition of activities carried out for the initial fresh core An example of a new core configuration is the introduction of mixed oxide fuel in the core with predominantly standard type of fuel bundles.

2.3.2 Collection and Updating of Baseline Information

2.3.2.1 The design and safety analysis information shall include:

(i) Detailed design of the fuel and its compatibility with the existing fuel specifications. In the case of a component, detailed design of the core component and material characteristics;

(ii) In the case of new fuel type, kinetics parameters such as delayed neutron fraction, reactivity coefficients and their impact on safety analysis, and

(iii) For new configuration or component, change of operational limits and conditions (OLCs) and its effect on reactor operation.

2.3.2.2 The baseline operating data collected for a new core configuration shall include items (i), (ii), (iii), (iv), (vii) and (viii) of sub-section 2.2.2.2.

2.3.2.3 All considerations mentioned earlier in sub-sections 2.2.2.3, 2.2.2.4 and 2.2.2.5 are also applicable here. In the absence of any earlier experience from similar reactors, procedures for introduction of new type of fuel or core component should be drawn afresh.

2.3.3 Prediction of Core Conditions

The predictions required for core management, in addition to those in subsection 2.2.4 shall include increase in fissile isotope concentration as a decay product during a shutdown. For a new type of fuel, projective multicycle studies should be done to ensure compliance with safety requirements.

2.3.4 Establishment and Implementation of Fuelling Programmes

Thc guidelines for establishment and implementation of fuelling programmes, in addition to those in 2.2.5 shall include inspection and tests after introduction of new type of fuel or core component.

3. HANDLING OF UNIRRADIATED/FRESH FUEL

3.1 Storage

3.1.1 Proper storage facilities shall be made available on site before any fuel is delivered to site. The Safety Guide on Design basis for Fuel Handling and Storage Systems in Nuclear Power Plants, (AERB/SG/D-24) provides guidance on design requirements for such facilities.

3.1.2 The fire risks in the new fuel storage area shall be minimised by avoidance of unnecessary accumulation of combustible material in the storage area. Fire-fighting instructions and fire-fighting equipment shall be readily available. The procedures to be followed if a fire occurs shall take care of proper extinguishing material and the need to isolate the ventilation system (Safety Guide on Protection against Fires and Explosions, AERB/SG/D-4).

3.1.3 Plant Management shall ensure that a designated person is responsible for receipt and control of the fuel on site, and that access to the store is limited to authorised personnel.

3.1.4 As soon as fuel is delivered to the fuel store, implementation of the relevant part of the Safety Guide on Radiation Protection during Operation of Nuclear Power Plants (AERB/SG/0-5) shall be initiated by appropriate radiation measurements.

3.1.5 In order to prevent critical configuration and to ensure integrity of the fuel elements, fuel shall be stored and handled only in an approved manner.

3.1.6 Transport containers shall be checked to see if they are properly identified and free from apparent damage. Storage arrangements should be such as to eliminate unnecessary handling as well as mixing up of different types of fuel bundles.

3.1.7 New fuel, after inspection and identification, should be stored vertically in the storage racks in the dry storage vault before being loaded into the core.

3.1.8 In the case of fresh fuel containing plutonium, special handling and storage procedures shall be followed.

3.2 Inspection and identification

3.2.1 Following receipt at the plant site and before loading, the fuel shall be inspected to verify that it is properly identified, and the documentation checked against this identification. The documentation should enable the assembly to be correlated with records which give information such as enrichment, fuel assembly no., fuel type, manufacturer, quality control history (which may affect the position in the core) etc.

3.2.2 Fuel shall be inspected by trained and qualified personnel in accordance with written procedures Detailed guidance shall be available to such persons on the damage that may be acceptable, and a record of any damage accepted by the examiner shall be maintained. All rejected fuel shall be treated as non-conforming in accordance with quality assurance requirements (Safety Guide on Quality Assurance in Procurement of Items and Services for Nuclear Power Plants (AERB/SG/QA-2)).

3 2.3 Inspection of the fuel shall include the checking of specified parameters such as bottom nose plate, tie-plate, condition of welded orifices etc. and any scratches on clad surface which may have occurred during transport and handling since previous inspectionat thelast works. In addition to the inspection on receipt, appropriate provisions to detect any subsequent damage shall be made prior to insertion into the core.

3.2.4 If fuel assemblies have to be repaired, technical and administrative precautions shall be taken to ensure that only the specified fuel assemblies are repaired, that the repair work is carried out according to written specifications (relating, for example, to the position, enrichment and burnable poison content in fuel elements) and that a critical configuration is not formed.

3.3 Precautions against Damage

3.3.1 To reduce the possibility of damage to fresh fuel during handling in storage area, only equipment designed for the purpose shall be used (AERB/SG/D-24) and suitably trained personnel under the supervision of a qualified person shall perform the fresh fuel handling activities.

3.3.2 Fuel handling procedures shall indicate the necessity of minimising stresses, particularly lateral, with emphasis on cases where they may be harmful to assemblies.

3.3.3 Any fuel suspected of damage during handling or storage shall be inspected and, if necessary, treated in accordance with procedures relating to damaged fuel (see 3.2.2).

3.3.4 When fuel is manually handled, suitable clothing shall be worn to prevent contamination of personnel (AERB/SG/0-5) as also to prevent damage and contamination to the fuel.

3.3.5 During transportation of fuel within the site, adequate precautions shall be taken to prevent damage to the fuel and contamination.

4. IMPLEMENTATION OF THE FUEL LOADING PLAN

4.1 Fuel Loading Plans

4.1.1 The fuelling programmes referred to in sub-section 2.2.5 are implemented by means of fuel loading plans which specify in detail the sequence of operations to be carried out. These plans shall specify the types of fuel and core components to be taken from store or from storage pool, the route they are to take and the positions they are to occupy in the core. The plan shall also specify the fuel to be shuffled or unloaded, its original position in the core, its new location either in the core or in the storage pool, the sequence for unloading and loading of fuel and other components such as control rods and the checks to be performed at each stage. A11movement of fuel from the store or storage pool to the core or from core to spent fuel bay shall be carried out in accordance with approved procedures.

4.2 Loading of Fuel and Core Components into the Reactor

4.2.1 Arrangements shall be made to obtain as much assurance 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 core location with correct orientation. Subcriticality checks to be performed shall be specified.

All operations involving fuelling of the reactor shall be carried out under the supervision of a person licensed for fuel handling operations. Shift Charge Engineer shall be qualified regarding the implementation of fuelling operations.

4.2.2 Some simplification of handling procedures may be possible when a reactor is being loaded with fuel for the first time. However, since fuel and core components have not been irradiated, compliance with the fuelling plan and the quality assurance requirements mentioned in the preceding paragraphs of this section shall be required. An additional precaution that shall be taken for the first load is to certify immediately before any new fuel is loaded into the core that all dummy or test assemblies used for commissioning purposes have been located and removed from the core and that no unauthorised equipment, component or material is in the reactor core. To this end, dummy or test assemblies, in particular, shall be made easily distinguishable from normal fuel.

Procedures including documentation shall be established to ensure that no unintended material is left in the reactor vessel before it is closed.

4.2.3 Any component (e.g., instrumentation, reactor-water flow regulator, control rod etc.) which forms part of or is attached to a fuel assembly requires inspection and checks as part of the loading procedure in accordance with the quality assurance requirements (see section 4.2.1). Core components which have not been included in the fuel loading plan shall require specific approval from the competent authority before they can be loaded into the reactor core.

4.2.4 Procedures shall be developed to cover the movement of any item into or out of the core. In the case of an item which is not part of the design covered by the safety report, such as samples of materials to be irradiated, the procedure shall require a thorough safety review of the item, its movement into and out of the core and its residence in the core.

4.2.5 When fuel is being loaded into the core, neutron flux shall be measured at specified stages. Changes in neutron flux shall be evaluated to prevent an unanticipated reduction in shutdown margin or inadvertent criticality. Shutdown margin verification tests shall be performed on the fully loaded core; it is desirable to perform the same tests at specified stages during fuelling.

4.3 Unloading of Irradiated Fuel and Core Components

4.3.1 Fuel shall be unloaded in accordance with written procedures.

4.3.2 On discharge, identification of fuel bundles or core components should be checked whenever practicable. Any error found either in the original loading or unloading shall be reported and a review undertaken by Plant Management to ensure that appropriate action is taken.

4.3.3 Procedures shall specify radiological protection precautions for handling unloaded fuel, core components and materials and any disassembly or reconstitution operations.

4.3.4 Any fuel known to have failed shall be dealt with in a suitable way, to reduce storage facility contamination as necessary and to enable applicable transport requirements to be met when it is subsequently shipped off-site. Any fuel suspected to have failed shall be considered as failed fuel until a thorough check shows otherwise.

Suitable means shall be provided for detection of defects in fuel during handling and for any necessary remedial actions.

4.3.5 Where applicable, unloaded fuel and core components should be examined before storage if any physical damage is suspected. For certain types of damage such as bowed assemblies, the core location previously occupied by the damaged fuel shall be examined and corrective measures taken, so that damage to fuel designated for loading into the same location can be avoided. Detection of damage to fuel or core components may require examination of adjacent components. Any repairs shall be performed on the basis of previously tested and accepted methods.

4.3.6 Rack locations in the storage facility should be examined before receiving unloaded fuel. The racks shall be maintained within the specified verticality tolerances to ensure that fuel assemblies are not stressed.

4.4 Precautions for Loading and Unloading of Fuel and other Core Components

4.4.1 As pre-requisites to ensure that a critical configuration is not unintentionally formed during fuel loading, nuclear start-up instrumentation, protection system interlocks etc. shall be checked before and, as appropriate, during loading process.

4.4.2 While handling fresh and irradiated fuel, procedures shall include necessary precautions to be taken to assure safety. Aspects to be considered include reactivity status, component integrity, heat dissipation and radiological protection including shielding.

4.4.3 The following precautions are taken to avoid open vessel criticality:

(i) Start-up neutron range flux detection system to be operable and connected to reactor protection system. When loading the new core, as the source counts are very low, neutron source counters with higher sensitivity shall be used. Response of source range monitors should be assured;

(ii) Control rods to be inserted in the core and rendered inoperable, if required. It shall not be possible for more than one control rod to be moved at a time, except in accordance with approved written procedures;

(iii) Reactor vessel and pool storage water level to be maintained above specified minimum levels;

(iv) The appropriate interlocks to be in the correct configuration and the necessary functional checks, calibrations, etc., carried out on the control rod drive circuit, reactor protection system and the fuelling equipment;

(v) Procedures to be established to ensure that items are not dropped into the reactor vessel;

(vi) Adequate communication links to be established between control room and fuel loading area; and

(vii) A licensed person to be in charge of loading/unloading of fuel.

4.4.4 Additional precautions to be taken during fuel handling operations are:

(i) Radiological protection controls and supervision to be established;

(ii) Containment integrity to be as specified for refuelling; and

(iii) Ventilation systems to be operable as specified.

4.4.5 A final check is made before vessel closure that the core has been correctly loaded (checking fuel and core component identification and orientation as applicable). It is advantageous to obtain video records for subsequent verification.

4.4.6 Aspects of component handling within the core which have safety implications include:

(i) Criticality arising, for example, from manipulation of control elements;

(ii) Physical damage to fuel and core components resulting from mishandling or dropping of components;

(iii) Damage to the core due to distortion, swelling or bowing of core components; and

(iv) Personnel exposure due to radioactivity of components or due to radioactive material released during handling.

5. IRRADIATED FUEL STORAGE

5.1 To ensure that fuel integrity and subcriticality are maintained, irradiated fuel shall be handled, stored and inspected only in approved facilities and using equipment approved for this purpose (Safety Guide on Fuel Handling and Storage Systems, AERB/SG/D-24) and in accordance with written procedures.

5.2 In particular, conformance with approved configurations, along with requirements for any neutron absorbers, is required for spent fuel pool. Specified neutron absorbers may be in the form of fixed absorber sheets in the storage pool water. Suitable quality assurance procedures shall be implemented to assure compliance with sub-criticality requirements.

5.3 In the case of storage under water, water conditions shall be maintained in accordance with specified values of temperature, pH, activity and other applicable chemical and physical characteristics to:

(i) Avoid corrosion of fuel, core components and structures in the pool by maintaining suitable pH values and other applicable chemistry conditions (e.g. halide ion concentration);
(ii) Reduce contamination and radiation levels in the pool area by limiting water evaporation and water activity; and
(iii) Facilitate fuel handling in the pool by maintaining water clarity (removal of particulates). Adequate underwater illumination shall be provided.

5.4 To avoid damage to fuel stored in the storage pool, the movement of heavy-objects above stored fuel which are not.-part of the lifting devices shall be prohibited unless case-by-case authorisation is obtained. The fuel handling equipment shall be checked to ensure correct operation prior to the start of fuel handling.

5.5 Storage facility areas shall be under radiological protection control (AERB/SG/0-5). Access shall be limited to authorised personnel with appropriate training and all operations shall be performed in accordance with approved written procedures.

5.6 Examples of precautions that shall be taken to limit radiological exposures in the case of pool storage include:

(i) Pool water level to be maintained between specified levels;

(ii) Radiation monitors to be provided and checked for operability and correct adjustment to ensure that they give an alarm if the radiation levels reach the pre-determined alarm setting;

(iii) Radiation levels at the water surface to be limited by use of approved procedures and tools which ensure that fuel is not raised too close to the water surface; hazards involving tools having long hollow parts to be avoided by provision of fill, vent and drain openings;

(iv) Correct operation of ventilation system to be ensured;

(v) Proper supervision and adequate training of personnel to be instituted; and

(vi) Access to fuel pool area to be on the basis of need only.

5.7 It is a good practice to maintain sufficient spare capacity in the irradiated fuel storage facility to accommodate one full charge of fuel and one full set of control rods at any given time (AERB/SG/D-24).

5.8 In the case of dry storage or storage under liquids other than water, appropriate safety procedures for aspects of sub-criticality, decay heat, flooding, neutron shielding etc. shall be established.

6. CORE COMPONENT HANDLING

6.1 Inspection, Storage and Handling of Core Components

6.1.1 All new core components shall be visually examined for physical damage before insertion into the core. Where appropriate, dimensional and functional checks shall be made to ensure that components are in proper state for their intended use. During handling and installation, checks should be made on undue constraints to identify any potential problems.

6.1.2 Each core component as applicable should be adequately identified and a record maintained of its core location, orientation within the core, out-of-core storage position, and other pertinent information such that an irradiation history of the component is available.

6.1.3 Aspects to be considered for storage of unirradiated components shall include prevention of physical damage, assurance of cleanliness and prevention of radioactive contamination.

6.1.4 For irradiated core components, the following aspects shall be considered:

(i) Proper tools and written procedures for handling;

(ii) Provision of adequate cooling;

(iii) Shielding and limitation of access to provide radiological protection;

(iv) Compatibility of the core component material and the storage medium; and

(v) Assessment for re-use and accessibility in case a component is to be re-used.

6.2 Surveillance and maintenance of irradiated components

6.2.1 Programmes shall be established for surveillance and maintenance, where appropriate, of core components during service (AERB/SG/0-7 and AERB/SG/0-8). Checks should be carried out for physical changes such as bowing, swelling, corrosion, wear, creep etc. The programme shall include examination of components to be returned to the core for further service, and examination of discharged components to detect significant degradation during service (Safety Guide on In-Service Inspection for Nuclear Power Plants, AERB/SC/O-2).

7. PREPARATION FOR IRRADIATED FUEL TRANSPORT

7.1 Fuel shall be removed from the storage facility only in accordance with an authorisation which identifies the fuel type and position in the facility.

7.2 Fuel shall be selected for loading into a fuel shipping cask on the basis of its irradiation history and cooling time so that the fission product inventory and decay heat level remain within the specified limits for the cask as well as inadvertent criticality will not occur during transportation. Procedures shall be established using techniques, such as check lists, to ensure that the fuel contents of shipping cask have been loaded as specified.

7.3 A procedure shall be established for preparation of transport container for transportation off-site. This shall ensure, in particular, that adequate leak tightness exists and contamination levels are sufficiently low to meet transportation requirements.

If it is necessary for the shipping cask to have special removable neutron absorber curtains or similar devices, procedures shall be established to ensure that these are in place before the fuel is put into the container.

7.4 The transport vehicle shall be checked for compliance with transportation requirements regarding external contamination and radiation levels before despatch from site.

7.5 Any previously used cask shall be assumed to contain radioactive substances and checked for contamination and radiation on arrival on site. If the levels of contamination or radiation are above specified values, the cause shall be investigated and corrective action taken.

7.6 Before a previously used and supposedly empty cask is opened, radiation monitors with alarms shall be checked to be operative. Suitable measures shall be taken (such as opening cask under water) t6 prevent accidental exposure of personnel in case significant radioactive sources remain inside.

7.7 Detailed guidance on the safety aspects of transport of radioactive materials can be found in the AERB Safety Code for Safety in Transport of Radioactive Materials, (AERB/SC/TR-I).

8. SURVEILLANCE RELATED TO CORE MANAGEMENT

8.1 Surveillance programme related to core management and fuel handling is intended for timely detection of any deterioration that could result in an unsafe condition of the reactor core. Surveillance activities include monitoring, checking, calibration, testing and inspection and shall be part of an overall surveillance programme to be formulated and implemented according to the recommendations contained in AERB/SG/0-8. The items particularly relevant to core management and fuel handling include:

(i) Safety and control systems (operability, actuation times and reactivity insertion and removal rates);

(ii) Instrumentation for measurement of parameters required for core monitoring (see-subsection 2.2.3);

(iii) Core and component cooling systems (e.g. coolant flow, pressure, temperature, activity and chemistry);

(iv) Fuel and core component handling systems (e.g. instrument checks, functional testing of interlocks); and

(v) Storage facility (e.g. checks on heat removal, activity levels and chemical, conditions and rack integrity).

9. ADMINISTRATIVE AND ORGANISATIONAL ASPECTS

9.1 Plant Management shall be responsible for all aspects of core management and on-site fuel handling. It is essential that adequate design support is provided to core management groups. The Operating Organisation shall ensure that Plant Management is given the requisite authority and support, and that responsibilities are clearly defined.

9.2 Organisational interfaces shall be identified, established and documented by the Operating Organisation. The documentation shall specify the information required, the persons responsible for its supply, review and comment requirements, and the approval needed.

When arrangements are made by RO to obtain some core management services from other groups within Operating Organisation itself or from other organisations, there shall be reasonable assurance that these services are made available in time.

Guidance for administrative controls is provided in the Code of Practice on Quality Assurance for Safety in Nuclear Power Plants (AERB/SC/QA) and the Quality Assurance Safety Guides.

9.3 The responsibilities of Operating Organisation relating to core management and fuel handling include the following arrangements (liaison with other organisations may also be involved):

(i) Ensuring from the design stage onwards that Plant Management is provided with necessary data, study reports, manufacturing, construction, commissioning and quality assurance documents to enable the plant to be operated in a safe manner and in accordance with design intent and assumptions;

(ii) Procurement of fuel, surveillance of its fabrication for adherence to specification in accordance with applicable quality assurance requirements (IAEA Safety Series No.50-SG-QAIl);

(iii) Ensuring that no modification to fuel assemblies, core components, handling equipment and/or procedures is carried out without proper consideration and formal approval if so required (AERB/SG/0-7);

(iv) Ensuring that necessary data and documents (see (i) above) are made available in a timely manner to Plant Management when modifications (see (iii) above) are introduced;

(v) Ensuring that core calculation methods are established and kept up-to-date to define fuel cycles, fuel and absorber loading patterns to maintain compliance with the applicable operational limits and conditions; to verify operating procedures and to establish associated surveillance requirements; and to achieve the optimum utilisation of fuel;

(vi) Examination of irradiated fuel for fuel performance evaluation;

(vii) Transportation of unirradiated and irradiated fuel and core components;

(viii) Storage and handling of unirradiated and irradiated fuel and core components on the plant site; and

(ix) Timely collection of information on experience and its dissemination to relevant personnel in RO and other associated agencies.

9.4 Procedures to be developed in relation to various safety aspects of core management and fuel handling shall include:

(i) Receipt, storage, handling, inspection and disposition of fuel and core components;

(ii) Recording of fuel and core component location, exposure, physical condition and disposition;

(iii) Core surveillance to meet core management requirements;

(iv) Tests to obtain core parameters such as those described in sub-section 2.2.3.1;

(v) Actions to be taken by plant operators whenever core parameters are outside specified limits and conditions for normal operation and actiontaken to prevent safety limits being exceeded;

(vi) Independent review of core performance and of proposals for significant modifications to plant items and procedures (AERB/SG/0-7); and

(vii) Reporting of unusual occurrences and their subsequent investigation by personnel not directly involved at a level appropriate to the significance to safety.

10. RECORDS

10.1 The baseline information detailed in subsection 2.2.2 shall be augmented during subsequent plant operation by a comprehensive record system covering core management, and fuel and core component handling activities. This record system shall be designed to provide sufficient information for correct handling of fuel and core components on site and for detailed analysis of performance of the fuel and activities related to core safety throughout the operating life of the plant. Guidance for record keeping is provided in the Safety Guide on Quality Assurance Records System for Nuclear Power Plants (IAEA Safety Series No. 50-SG-QA2).

10.2 Typical records important to core management, and fuel and core component handling shall include the following, as applicable:

I. Plant operational records

(i) Data relating to commissioning tests (baseline information, subsection 2.2.2.2) and records of special operating tests;

(ii) Core operating history (typically, hourly log of temperature, flow, etc. from plant computer);

(iii) Power, energy, and heat balance;

(iv) Reactivity balance;

(v) In-core flux measurements;

(vi) Fuelling programmes and supporting information;

(vii) Location of each fuel bundle throughout its residence on site;

(viii) Individual fuel bundle power versus burnup;

(ix) Fuel failure data;

(x) Fuel and component examination results;

(xi) Fuel and component handling equipment status, repair, modifications, and test results; and

(xii) Coolant and moderator inventories, and chemical quality impurities.

II. Core management records:

(i) Computer calculations of core parameters, power and neutron flux distributions, isotopic changes, and additional data considered important to fuel performance;

(ii) Recommended fuelling patterns and schedules and as implemented fuelling patterns and schedules;

(iii) Design basis, core material properties and dimensions;

(iv) Test result comparisons and validation of computational methods;

(v) Operational data to validate methods, to provide input forfuelling plan and to form the basis for operational safety evaluation.

10.3 Lessons gained from experience and related to safety can enhance safe operation. Therefore, information obtained from fuel operating experience should be recorded and exchanged between plant managements within the Operating Organisation and with other operating organisations, particularly those operating similar reactors.

ANNEXURE-I

BASELINE INFORMATION RELATING TO CORE MANAGEMENT

The baseline information relevant to core management includes as applicable:

A.I.1 Reactor Data

1. Cold clean core data at initial fuel loading giving fuel pattern, loading map with fuel and channel numbers;
2. Radial flux values;
3. Axial flux values;
4. Control rods;
5. Predicted criticality condition;
6. Insertion & withdrawal of control rods;
7. Shutdown system involving liquid poison injection (poison concentration, valve opening time, injection time);
8. Start-up instrumentation and neutron flux instrumentation overlap requirements;
9. Calibration of neutron flux instrumentation and core instrumentation and response time measurements;
10. Poison addition system performance;
11. Control rod system worth;
12. Feed water flow and steam flow; and
13. Steam flow and pressure.

A.I.2. Core Conditions

1. Control/Moderator temperature coefficient of reactivity;
2. Fuel temperature coefficient of reactivity (Doppler);
3. Heat balance;
4. Power, flux, and temperature distributions;
5. Power coefficient of reactivity;

6. Temperature and void coefficients of reactivity;

7. Maximum linear heat rate or-equivalent; and

8. Major saturation fission product data.

A.I.3 Reactor Coolant

1. Temperatures: coolant inlet; coolant outlet; temperature;

2. Core coolant flow rate (total and in-channel flows, pump characteristics;

3. Core coolant pressure;

4. Coolant chemical quality and impurity concentration and composition; and

5. Fission product activities in primary coolant.

A.I.4. For calculating core thermal power, parameters such as feed water flow, feed water temperature, primary steam flow, feed temperature and pressure, reactor pressure and cleanup flow should be used.

ANNEXURE-II

COMPUTER CODES FOR CORE MANAGEMENT

A.II.1 General

The computer codes used for core management should have been validated and should be available at the plant site. The personnel using the codes at the plant site should be knowledgeable about the codes and should have been trained to use them. The following codes should be used for core management activities.

A.II.1.1 Boiling Water Reactors

A.II.1.1.1 Reactor Simulator:

A computer code to simulate the reactor operation as closely as possible and to follow up the reactor operation at the plant site should have the following features:

1. Calculation of reactivity and three-dimensional power, exposure and void in the core;

2. Calculation of isotopic composition of fissile isotopes in each bundle and in the core; and

3. Output in the form of keff of the core, exposure of all fuel bundles, depletion of control rods, radial factors, axial factors, thermal parameters like Peak Heat Flux, Minimum Critical Heat Flux Ratio (MCHFR).

ANNEXURE-III

RELOAD PATTERN

Reload pattern means the arrangement of irradiated bundles of the previous cycle and fresh fuel in the new core configuration to achieve desired power level and cycle length from the reloaded core.

Before the start of a new cycle operation, an optimised reload pattern and control rod pattern are generated. The inputs for this calculation include number of failed bundles from the previous cycle, exposures of fuel bundles at the end of the previous cycle, cycle length and power level of the new cycle, control rod depletion, etc. The output is in the form of arrangement of old and new bundles in the new cycle for achieving desired cycle length with optimum power distribution without violating thermal limits and ensuring desired shutdown margin. Precautions to be taken while assembling the new core are covered in section 4.4.

Thermal limits on fuel include limits on peak heat flux (PHF) and minimum critical heat flux ratio (MCHFR). PHF takes care of limits on the fuel centreline temperature, while MCHFR takes care of fuel clad integrity.

ANNEXURE-IV

VERSIONS OF BOILING WATER REACTORS

Boiling Water Reactor (BWR) technology is claimed to be attractive due to its basic simplicity and potential for greater thermal efficiency, better reliability, load following capability and lower capital cost.

BWR designs have changed gradually from its inception. Basic differences in the design of different BWRs were mainly based on natural and forced circulation of the coolant/moderator and direct steam cycle/indirect steam cycle/dual steam cycle.

In direct cycle the steam produced in the core directly goes to the turbine, whereas in indirect cycle, steam generators are used to produce the required steam. Dual cycle is the one with both direct and indirect cycle.

Normally either direct cycle or dual cycle of BWRs are preferred, designed and are in operation. Due to increased cost and maintenance associated with large steam generators and requiring relatively high operating pressures on the primary side, the indirect cycle type of BWRs have not become popular.

The dual cycle design was chosen because of its combined reliability, stability, and fairly high power density with a well controlled reactor response to load changes because the principle of subcooling control is used during "load follow". However, these plants require relatively higher capital cost and maintenance expense associated with steam generators.

Direct cycle BWRs have been preferred because of its simplicity and thermodynamic potential. Subsequent generation reactors are of direct cycle with improved emergency core cooling system, fuel bundles of 7 x 7 or 8 x 8 and usage of internal jet pumps in coolant/moderator system along with variable coolant flow control. The following table gives salient features of various BWRs:

Reactor Type	**Salient features**
BWR/1	Dual cycle, direct-cycle prototype natural circulation, pressure suppression containment, and first internal steam separation.
BWR/2	Pressure suppression containment, direct cycle, flow control, and 7 x 7 fuel bundle.
BWR/3	Features of BWR/2, internal jet pumps, and improved emergency core cooling system (ECCS).
BWR/4	Features of BWR/3 and increased power density (20%)
BWR/5	Features of BWR/4 and improved safeguards valve flow control.
BWR/6	Features of BWR/5, 8 x 8 fuel bundle, improved ECCS performance and reduced fuel rating.

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2. Design for Reactor Core Safety in Nuclear Power Plants IAEA Safety Series No. 50-SG-D14

3. Quality Assurance Records System for Nuclear Power Plants IAEA Safety Series No. 50-SG-QA2

4. Quality Assurance in Procurement, Design and Manufacture of Nuclear Fuel IAEA Safety Assemblies Series No. 50-SG-QA11

5. Safety Aspects of Core Management and Fuel Handling in Nuclear Power Plants IAEA Safety Series No. 50-SG-O10

II. AERB Safety Codes and Guides:

1. Code of Practice on Safety in Nuclear Power Plant Operation AERB/SC/O

2. Code of Practice on Quality Assurance for safety in Nuclear Power Plants AERB/SC/QA

3. Code of Practice on Design for Safety in Pressurised Heavy Water Based Nuclear Power Plants AERB/SC/D

4. Code of Practice for Safety in Transport of Radioactive Materials AERB/SC/TR-1

5. In-service Inspection for Nuclear Power Plants AERB/SG/O-2

6. Operational Limits and Conditions for Nuclear Power Plants AERB/SG/O-3

7. Commissioning for Nuclear Power Plants AERB/SG/0-4

8. Radiation protection during Operation of Nuclear Power Plants AERB/SG/O-5

9. Maintenance and Modifications of Nuclear Power Plants AERB/SG/O-7

10. Surveillance of Items important to Safety in NPPs AERB/SG/O-8

11. Protection against Fires and Explosions AERB/DSG/0353.1

12. Design Basis for Fuel Handling and Storage Systems AERB/SG/D-24

13. Testing and In-service Inspection of Spent Fuel Handling and Storage Systems AERB/SG/D-26

14. Quality Assurance in Procurement of Items and Services for Nuclear Power Plants AERB/SG/QA2

LIST OF PARTICIPANTS

WORKING GROUP

Dates of Meeting:	April 16, 1996 April 24, 1996 June 25, 1996	September 5, 1996 October 25, 1997 January 10, 1998

Shri R. Srivenkatesan	: BARC
Shri F.M.Ghanbahadur	: NPC
Shri S.N.Rao	: AERB
Shri D.P.Burte	: BARC
Shri A. Ramakrishna (Member-secretary)	: AERB

Advisory Committee on Codes, Guides and Associated Manuals for Safety in Operation of Nuclear Power Plants (ACCGASO)

Date of Meeting : January 10, 1998

Members and alternates participating in the meeting:

Shri G.V. Nadkarny (Chairman)	: Formerly Director E&PA, NPC
Shri V.S. Srinivasan	: NPC
Shri Y.K. Joshi	: RAPS/NPC
Shri Ravindranath	: TAPS/NPC
Shri V.V. Sanathkumar	: MAPS/NPC
Shri R.S. Singh	: AERB
Shri Ram Sarup	: AERB
Shri S.T. Swamy (Co-opted)	: AERB
Shri S.K.Warrier (Member-Secretary)	: AERB

Date of Meeting	: November 28, 1998

Members and alternates present in the meetings:

Shri S.K. Mehta	: Former Director, Reactor Group, BARC
Shri S.M.C. Pillai	: Nagarjuna Power Corp.
Shri S. K. Goyal	: BHEL
Prof.U.N. Gaitonde	: IIT, Bombay
Shri Ch. Surendar	: NPC
Dr.U.C. Mishra	: BARC
Shri S.K. Sharma	: BARC
Dr.V. Venkat Raj	: BARC
Shri S.P. Singh	: Former Head, NSD, AERB
Shri G.K. De	: AERB
Smt. Usha A. Menon (Member- Secretary)	: AERB
Shri G.V. Nadkarny (Invitee)	: Formerly Director E&PA, NPC
Shri S.K. Warrier (Invitee)	: AERB

PROVISIONAL LIST OF SAFETY GUIDES ON OPERATION OF NUCLEAR POWER PLANTS

Title	**Safety Series No.**
AERB/SG/O-1	Training and Qualification of Operating Personnel of Nuclear Power Plants
AERB/SG/O-2	In-service Inspection for Nuclear Power Plants
AERB/SG/O-3	Operational Limits and Conditions for Nuclear Power Plants
AERB/SG/O-4	Commissioning for Nuclear Power Plants
AERB/SG/O-5	Radiation Protection during Operation of Nuclear Power Plants
AERB/SG/O-6	Preparedness of the Operating Organisation for Emergencies at Nuclear Power Plants
AERB/SG/O-7	Maintenance and Modifications of Nuclear Power Plants
AERB/SG/O-8	Surveillance of Items important to Safety in NPPs
AERB/SG/O-9	Management of Nuclear Power Plants for Safe Operation
AERB/SG/O-10A	Core Management and Fuel Handling in Operation of Pressurised Heavy Water Reactors
AERB/SG/O-10B	Core Management and Fuel Handling in Operation of Boiling Water Reactors
AERB/SG/O-10C	Core Management and Fuel Handling in Operation of Pressurised Water Reactors
AERB/SG/0-11	Management of Radioactive Waste Arising during Operation of Nuclear Power Plants
AERB/SG/0-12	Renewal of Authorisation for Operation of Nuclear Power Plants.
AERB/SG/0-17	Operational Experience Feedback for Nuclear Power Plants