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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

CORE MANAGEMENT AND FUEL HANDLING IN OPERATION OF

PRESSURISED HEAVY WATER REACTORS

ATOMIC ENERGY REGULATORY BOARD

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AERB Safety Guide No.AERB/SG/O-10 A

CORE MANAGEMENT AND FUEL HANDLING IN OPERATION OF PRESSURISED HEAVY WATER REACTORS

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FOREWORD

Safety of public, occupational workers and the 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 standards has been of prime importance since the inception of the 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 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 of 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 the 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 developments in the field. The annexure, foot-notes and references are not to be considered integral part of the document. They are included to provide information that might be helpful to the user.

The emphasis in the codes and guides is on the protection of site personnel and public from undue radiological hazard. However, for aspects not covered in the codes and guides, applicable and acceptable national and international codes and standards shall be followed. Industrial safety shall 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.

(i) The 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 Pressurised Heavy 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 Nuclear Power Plants 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 developed under the NUSS programme, specially IAEA Safety Guide on "Safety Aspects of Core Management and Fuel Handling for Nuclear Power Plants" (50-SG-O10).

This safety guide has been reviewed by experts and vetted by the AERB Advisory Committees 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, alongwith their affiliations, is included for information.

(P.Rama Rao)
Chairman, AERB

DEFINITIONS

Acceptable limits
Limits acceptable to AERB for Accident Conditions.

Accident conditions [1]Substantial deviations from Operational States which are expected to be infrequent, and which could lead to release of unacceptable quantities of radioactive materials if the relevant engineered safety features did not function as per design intent.

Anticipated Operational Occurrences [2]
All operational processes deviating from Normal Operation which are expected to occur once or several times during the operating life of the plant and which in view of appropriate design provisions, do not cause any significant damage to Items Important to Safety nor lead to Accident Conditions (see Operational States).

Approval
Formal consent to a proposal.

Atomic Energy Regulatory Board (AERB)
National authority designated by Government of India, assisted by technical and other advisory bodies, and having the legal authority for conducting the authorisation process, for issuing authorisation and thereby for regulating nuclear power plant Siting, Construction, Commissioning, Operation and Decommissioning or specific aspects thereof.

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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, loss of power to main coolant pump.

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 the irradiation of the composite. In the context of this guide the 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 plant components and systems, having been constructed, are made operational and verified to be in accordance with design assumptions and to have met the performance criteria; it includes both non-nuclear and nuclear tests.**

Core components
All items other than fuel, which reside in the core of an NPP and have a bearing on fuel integrity and utilisation. (e.g., calandria, moderator, coolant channels, incore detectors, reactivity devices etc.)

Core management
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 the same.

Documentation [5]
Recorded or pictorial information describing, defining, specifying, reporting or certifying activities, requirements, procedures or results.

Emergency situation
A situation which endangers or threatens to endanger safety of Site personnel, the NPP or the environment and the public.

Equilibrium core condition
The condition of the core in which the rate of charging and discharging of the fuel in the core, averaged over a period of time, reaches and remains close to the relevant design value.

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

4 **The 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.**Examination
An element of Inspection consisting of investigation of materials, components, supplies, or services, to determine conformance with those specified requirements which can be determined by such investigation.

Fuel bundle
A grouping of fuel elements and supporting structures which is normally treated as a unit for handling and purposes of accounting.

Fuel element (Fuel pin/Fuel rod)
A component (rod, pin, cylinder, plate 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 dispatch from the NPP.

Inspection

Quality Control actions which by means of 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 radiation exposure of the Site Personnel or members of the public.[6]

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

(3) those features which 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 release of radioactivity from nuclear facilities.**

Normal operation

Operation of a Nuclear Power Plant within specified Operational Limits and Conditions including shut-down, power operation, shutting down, starting up, mainten-ance, testing and refueling (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. heat or electricity.

Operation[4]

All activities performed to achieve, in a safe manner, the purpose for which the plant was constructed, including maintenance, refueling, In-Service Inspection, Environmental monitoring and other associated activities.

Operation Code

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

Operational Limits and Conditions (OLCs)

A set of rules approved by AERB which set forth parameter limits, the functional capability and the performance levels of the equipment and personnel for safe operation of the NPP.

Operating organization[7]

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

Operating personnel

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

Operational records

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

Operational states

The states defined under Normal Operation and Anticipated Operational Occurrences (see Normal Operation and Anticipated Operational Occurrences).

Plant management
The members of Site Personnel who have been delegated responsibility and authority by the Responsible Organisation or Operating Organization for directing the Operation of the plant.

Poison (Nuclear poison)
A substance which, because of its high neutron-absorption cross- section, can reduce reactivity.

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7 In the present context, Directorate of Operations, NPCIL is the Operating Organization. **Prescribed limits**
Limits established or accepted by AERB for Operational States.

Protection system
A system which encompasses all those electrical and mechanical devices and circuitry, from and including the sensors upto the input terminals of the safety actuation system and the safety system support features, involved in generating the signals associated with the protective 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.

Quality control [5]Quality Assurance actions which provide a means to control and measure the characteristics of an item, process or facility in accordance with established requirements.

Reactivity
A parameter, generally designated as Rho, giving the deviation from the criticality of a nuclear chain reacting medium such that positive values correspond to a supercritical state and negative values to a subcritical state. Quantitatively,

Rho = 1- 1/k-eff

where k-eff(k-effective) is the effective multiplication factor. Reactivity is expressed in terms of milli-k (10^{-3}k). Other units that are used are dollar, cent, inhour and pcm etc.

Records
Documents which furnish objective evidence of the quality of items and of activities affecting quality.

Responsible Organization (RO) [8]
The organization having overall responsibility for siting, design, construction, commissioning, operation and decommissioning the NPP.

Safety
The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences resulting in protection of site personnel, the public and the environment from undue radiation hazards.

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8 In the present context Nuclear Power Corporation of India Limited (NPCIL) is the Responsible Organisation for Nuclear Power Plants in India. **Safety limits**
Limits upon process variables within which the operation of the NPP has been shown to be safe.

Safety systems

Systems important to Safety, provided to assure , in any condition, the safe shutdown of the reactor and the heat removal from the core, and /or to limit the consequences of Anticipated Operational Occurrences and Accident Conditions (See Anticipated Operational Occurrences and Accident Conditions).

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

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

Site personnel
All persons working on the Site, either permanently or temporarily.

Shutdown margin
Minimum specified reactivity margin by which reactor should be subcritical even in the most reactive condition of the core for all anticipated operational occurrences and accidental conditions taking into account postulated unavailability of shutdown devices.

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 operation of the NPP and approved by AERB.

Testing
The determination or ascertaining 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.

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

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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 operational aspects of pressure-tube type Pressurised Heavy Water Reactors (PHWRs). The Guides AERB/SG/0-10 B&C deal with the core management and fuel handling aspects for BWRs and PWRs respectively.

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 (calandria, end-shields, and pressure tubes), shutoff rods, adjuster rods, fuel bundles etc. 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, while using the associated moderator, coolant, regulating, protective, fuelling systems, are included in the Safety Guide on Operational Limits and Conditions (AERB/SG/O-3).

1.1.5 The term 'fuel handling' in this Safety Guide includes in-core and out of core movement of unirradiated and irradiated fuel, its storage, preparation for its dispatch and onsite fuel transportation.

1.1.6 Design aspects related to reactor core and its components including fuel assemblies are considered in Code of Practice on Design for Safety in PHWR based NPPs (AERB/SC/D).

1.1.7 The Responsible Organisation (R.O) shall ensure that satisfactory administrative arrangements are made for the 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.

1.1.8 The Plant Management shall ensure that satisfactory administrative controls are established among the operating, technical and maintenance groups of the plant in such a way 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 so as to ensure the integrity of the fuel and core components during startup, power operation, shutdown and refuelling. The focus is on the management of reactivity and power distribution in the core in such a manner that under no circumstances an uncontrolled increase in power occurs and ensuring always that a specified shutdown margin and hence safe shutdown capability is 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 emphasize the necessity for establishing the procedures for detecting the failed fuel bundles in the core and for taking prompt remedial action such as coolant purification and on-power fuel replacement as necessary.

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

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

1.3 **Scope:**

1.3.1 This Safety Guide describes the safety objectives of core management, the tasks which have 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, neutron absorbers, coolant channel and its components, etc. However, this Guide does not cover accident/post-accident scenarios arising out of either coolant voiding or loss of regulation.

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 natural uranium fuel to MOX fuel or from stainless steel adjusters to cobalt adjusters. 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 organisation 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.

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 required safety margin. Efficient and safe use of reactor fuel 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 parametersimportant to safety, within specified limits by timely assessment, verification, monitoring and control, specially in relation to nuclear and thermal effects.

(ii) Implementing fuelling plans, to achieve efficient utilisation of fuel and optimum core performance while ensuring control of reactivity and integrity of fuel.

(iii) Core management schemes following detection and identification of failed fuel

(iv) Core management schemes following surveillance and in- service inspection of core components.

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) Compliance with channel selection rules (see section 2.2.5.2)

(iii) Reactivity shutdown margin

(iv) Heat transfer and coolant flow

(v) Reactivity addition and removal rates

(vi) Coefficients of reactivity

(vii) Neutron kinetic parameters

(viii) Characteristics of regulating and safety systems

(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) Nuclear heating magnitudes of core internals,

(xii) Coolant/Moderator chemistry,

(xiii) Control of fission product activity in the primary coolant sytem,

(xiv) D_2/O_2 content of cover gas system,

(xv) Moisture content in Annulus gas system.

2.1.4 **Miscellaneous**

In order to ensure safe use of the fuel in the core, the core management should include:

(i) Assessment of the safety implications of any component or material proposed to be inserted into the core,

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

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

2.2 **Core management activities**

2.2.1**General:**

The Responsible Organisation shall organise to implement the following activities to facilitate the basic tasks of subsection 2.1.2 ;

(i) Collection and updating of baseline information onnuclearfuel 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 of fuel management programmes,

(v) Establishment of monitoring programmes and criteria for detection, assessment and removal of failed fuel,

(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 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 the 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 equipments 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) Results of thermal hydraulic analyses and related limits during steady-state operation, anticipated transients and design basis accident conditions, (eg. LOCA)

(iv) Calculation of the following parameters for the initial core, approach to equilibrium and equilibrium conditions*:

(a) Reactivity of the core, reactivity worth of controlling devices (control rods,moderator level) andreactorshutdowndevices (shutoff rods, moderator dump, poison injection),

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*The presence of depleted uranium or thorium bundles, if any, should be accounted for.

(b) Shutdown margin under all operational states and accident conditions,

(c) Location and reactivity worth of the most effective control/shut off rods or banks,

(d) Reactivity coefficients of the core due to variations in temperature, power and void during the operational states,

(e) Neutron flux and power distribution in the core and within the fuel assemblies and their control by suitable movement of control rods or zonal absorbers.

(f) Reactivity worth of control rods as a function of their position and of poison as a function of its concentration.

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

(vi) Heat generation in fuel, in other core components, and in the moderator,

(vii) Assessment of irradiation effects on core components,

(viii) Assessment of irradiation-induced reactivity changes in control rods and sensitivity changes in the in-core instrumentation

(ix)Assessment of reactor dynamics (instability due to xenon).

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

(i) Initial fuel loading pattern giving type, serial number and location in core of fuel bundles.

(ii)Measured parameters for comparison with design estimates, such as core reactivity, neutron flux, channel outlet temperature distribution etc. as mentioned in Subsection 2.2.2.1

(iii) Assessment of neutron absorption characteristics of control and shutdown devices,

(iv) Calibration data for neutron flux instrumentation and other core instrumentation considering change in sensitivity caused by neutron fluence during the operation, when required,

(v) Heat balance,

(vi) Actuation time of shutdown devices (for estimation of power decay) such as, moderator dump valve opening time, shutoff rod insertion time and poison injection time etc.

(vii) Maximum possible rates of removal and insertion of control devices, such as regulating rods, moderator addition, poison addition, etc. taking into account actuation delays.

(viii) Coolant channel flow (measured/estimated),

(ix) Channel temperature rise,

(x) Radiation levels at specified locations,

(xi) Fission product activity in coolant,

(xii)Moisture in Annulus gas monitoring system.

(xiii)Activity in Annulus Gas Monitoring System.

A more detailed list of baseline operating data is given in Annexure-I.

2.2.2.3 The commissioning programme (preoperational tests, fuel loading, initial criticality and low power tests, high power tests) shall ensure that all baseline operating data are collected. Suitable tests shall determine parameters such as actuation times of fast-acting shutdown devices, absorber reactivity worth, flux measurement, and power measurement. Safety Guide on **"Commissioning of Nuclear Power Plants",(AERB/SG/O-4)** provide a guideline on tests which shall be considered for this stage in the programme.

2.2.2.4 The baseline data referred to in Subsection 2.2.2.2 above (see also Annex I) shall be compared, to the extent practicable, with design predictions. Significant discrepancies between the design and measuredvalueswith regard to any parameter shall be investigated in order to evaluate the safety implications and establish the cause for the discrepancies. Corrective actions, including possible modifications of the methods of design calculation or measurement, shall be taken as dictated by the conclusions of such an investigation.

2.2.2.5 Applicable experience from similar reactors 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 startup, power operation, shutdown, testing and fuelling, core parameters shall be monitored to determine whether core conditions conform to operational limits and conditions **(AERB/SG/O-3)** and, if they do not conform, appropriate actions shall be initiated to maintain the reactor in the safe condition. The results of core monitoring and testing shall also be applied to optimise channel selection and core performance.

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

(i)Neutron flux, axial and radial neutron flux peaking factors, flux profiles based on incore detectors,

(ii) Rate of change of neutron flux,

(iii)Positions of individual reactivity control devices, operability as per design intent, poison concentration in moderator, moderator level in calandria,

(iv) Reactivity worth of control devices as a function of their position or moderator level,

(v) Moderator level co-efficient,

(vi) Drop time for shut off rods, filling time for liquid poison tubes, dump valve opening time, dumptime, poison injection time in moderator,

(vii) Coolant pressure, flow, temperature rise, coolant outlet temperature,

(viii) Flow and temperature measurement in selected (instrumented) channels,

(ix) Average zone coolant outlet temperatures, power tilt factors,

(x) Thermal power output from the core, heat generation in moderator,

(xi) Moderator inlet and outlet temperature,

(xii) Fission product activity in the primary coolant and activity in moderator, moderator cover gas, and reactor vault water etc.,

(xiii) Purification flow for primary coolant,

(xiv) Chemical parameters of the moderator and primary coolant such as pH, conductivity, amount of crud and the concentration of impurities and products of radiolytic decomposition,

(xv) Isotopic Purity of coolant and moderator.

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

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

2.2.3.3 At various powers, parameters such as coolant temperatures, coolant pressure, instrumented channel coolant flow rate and neutron flux as a function of core power should be measured and displayed to the operator. For operation at reduced power or in the shutdown state, consideration may be given to the need to adjust the set points for alarm annunciation or safety action initiation in order to maintain the appropriate safety margins. (see 7.5 of AERB/SC/O, 1989). The values of parameters specified for use by the operator should be given in terms of instrument indications.

2.2.3.4 In many cases the parameters important to safety that affect fuel behavior 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. For example, parameters depending on burnup of the fuel such as bundle power are obtained by computer simulation based on operational data.

2.2.3.5 The values of parameters such as those related to chemical control are derived from direct measurements or from periodic analyses of samples of coolant, moderator or cover gas. The operating personnel shall be informed of the results of these analyses at frequent intervals. To avoid values of such parameters from going outside the specified range, the operating personnel shall be provided with instructions concerning the proper actions 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 burnup and refuelling operations, the core reactivity and power distribution changes with respect to time. This necessitates movements or changes of configuration of reactivity controlling devices, with consequent effects on power distribution, peak fuel power and the criticality configuration and conditions at startup. These changes and the consequent effects shall be predicted for both steady-state and transient conditions (Annexure-II). 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 condition and investigations to determine the cause of the discrepancy shall be carried out. The predictions required for purposes of core management include, as applicable :

(i) Variations in core reactivity with irradiation of the fuel,

(ii) Expected core conditions (reactivity control devices, moderator level, poison concentration) for criticality and the recommended steps needed to approach and achieve such conditions,

(iii) Changes resulting from operation (including refuelling) in parameters relating to the core conditions of subparagraphs 2.2.2.1 (iii, iv, v, viii).

(iv) Actions needed to maintain core reactivity by, for example, changes in control device positions, dissolved poison, moderator level and temperature, coolant temperature, fuelling rate etc. Such actions shall be analysed to ascertain that they do not adversely affect flux and power distribution in the fuel bundles or flux level at the core monitoring devices in the core,

(v) Reduction in control effectiveness and structural degradation of control devices due to irradiation effects,

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

(vii) Neutron source level, response and sensitivity and location of neutron detectors for startup, particularly after a long shutdown to check for adequacy.

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, specified bundle power, critical channel powers, and channel power 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 be taken 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 predicted values include, as applicable :

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

(ii) Neutron flux,

(iii) Moderator, fuel, fuel cladding, core component and core coolant temperatures,

(iv) Control device position and moderator level,

(v) Power sharing among coolant loops, if applicable

(vi) Coolant channel flows,

(vii) Coolant and moderator chemical conditions having a bearing on reactivity

2.2.5 **Establishment and implementation of fuelling programmes**

The initial fuelling programme should include details of fuel loading pattern in the core taking into account the reactivity device configurations. For subsequent refuelling programme, the selection of channel is based on consideration of reactivity, fuel burnup, outlet temperature, etc.

2.2.5.1 Whileachieving rated full power and targetfuel burnup, and providing sufficient reactivity to compensate for fuel depletion and fission product build-up, the safety objectives of the fuelling programme shall be met throughout the life of the reactor starting from the stage of initial fuel loading. These safety objectives include:

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

(ii)Meeting shutdown margin requirements.(Ref:SG/D7)

2.2.5.2 Aspects that shall be considered in the establishment and use of a fuelling programme (see also Annexure A.II.2.3) include, as applicable:

(i)Fuel burnup and consequent structural and metallurgical limitations,

(ii)Temperatures of coolant and fuel cladding in relation to flux distribution, channel flow and absorber configuration,

(iii) Increase in power output from a fuel bundle in the channel being refuelled and the neighbouring channels either during on-load refuelling or during power escalation; this may impose a restriction on the rate of rise of reactor power or the time for which the fuel bundle can withstand a power increment,

(iv) Flux tilt - and reactor stability within the capability of control system

(v)Mechanical capability of fuel bundles to withstand reactor core conditions and fuelling operations, particularly for reshuffling and re- using of irradiated fuel bundles

(vi)Fuel handling system availability and capability

(vii)Special considerations which may require restrictions on particular fuel bundles such as limitations of power output

(viii)Changes arising from the removal of failed fuel

(ix)Selection of channels to maintain radial and axial symmetry of power distribution

(x) Any changes in flux distribution caused by a change in core configuration such as defuelling of channel or stuck reactivity device.

2.2.5.3 The criteria regulating the fuelling programme shall be pre-established. Verification of compliance with all applicable operating limits and conditions shall be made. Should significant deviations from the established programme occur, a safety assessment of the new core conditions shall be made and consequent appropriate actions taken. Predictive simulation before each refuelling should be carried out for verification of compliance at site. The core predictions required for thepurpose of assessments are given in section 2.2.4.

2.2.5.4 During normal operation, results of calculated core simulations and their comparison with core performance with actual operating conditions (previous fuelling operations and present reactivity devices positions) should be readily available. These should be used as a basis for planning subsequent fuelling programme through additional core simulation calculations to meet specified safety criteria. The fuelling programme should be limited for refuelling only 2 to 3 channels, to implement the programme with adequate confidence. In addition, data such as fuel burnup, core reactivity, bundle and channel power and neutron flux should be updated, after implementing the fuelling programme.

2.2.5.5 Normally, shutdown refuelling should not be done because of the absence of reactivity feedback effects. In case shutdown refuelling becomes necessary, predictive simulations should be done in order to ensure compliance with power peaking and power ramp criteria when the reactor is started. Requirements on shutdown margin should be met in such cases.

2.2.6 Failed fuel

2.2.6.1 Fuel failure is indicated by increases in fission product activity above the normal value in the primary coolant. Fission product activity monitoring in the coolant 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. (Ref: AERB/SG/D6).

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

2.2.6.3 A reference level should be used to specify an upper limit on the fission product activity in the coolant above which a fuel failure is suspected to have occurred. Where applicable, a scanning system (such as a delayed neutron monitoring system) shall be put into operation to locate the failed fuel. The scanning system should have provision 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. Operating instructions shall provide predetermined levels at which subsequent actions should be taken in accordance with the indicated severity of the failure. Failed fuel should be unloaded so that the background fission product activity remains 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 (e.g.,formation of oxide or hydride mounds). The fuelling plan shall be reviewed to establish whether it needs to be modified as a result of unloading of the failed fuel.

2.2.7 Safety requirements to be included in operating procedures

2.2.7.1 Operating procedures on reactor startup, power operation, shutdown and fuelling need to include constraints necessary for the maintenance of fuel integrity and compliance with operational limits and conditionsthroughout the life of the fuel**(AERB/SG/O-3)**.

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 burnup orfuelling

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

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

(v) Limits for the chemical parameters (see section. 2.2.3.1(xiv) of the primary coolant

(vi) Limits for the chemical parameters of moderator when any gadolinium compound is used as dissolved poison

(vii) Adherence to power raise procedures depending on core conditions

(viii) Limits on flux peaks and flux tilt

(ix) Limits on bundle power as a function of burnup, power ramps during refuelling and/or due to changes in control device positions

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

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

(xii) Identification and replacement of faulty incore neutron flux detectors.

2.2.8 **Core management prior to coolant channel replacement**

The following should be taken into consideration while planning the defuelling for coolant channel replacement.

1. The burnup of the bundles to be discharged from the reactor core is to be maximised so as to extract the maximum possible energy from the fuel.

2. During defuelling of channels the PHT flow increases in empty channels and reduces the other channels. The sequence of defuelling should be decided taking this into consideration.

3. Sufficient storage space should be available for the discharged fuel and this should be planned properly.

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 introduction of mixed oxide or thorium fuel in the core with predominantly standard type of fuel bundles. A major core component change would take place when all the coolant tubes would be replaced. Another example is defuelling of one or more channels resulting from unacceptable displacement of garter springs. Replacement of coolant tubes, either completely or in installments, would result in substantially different core configuration. Such configurations may require repetition of many core management activities as for first criticality.

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 channel specifications as well as existing fuelling machine, when applicable. In the case of a component, detailed design of the core component and material characteristics

(ii) For the case of new fuel type, the kinetics parameters such as delayed neutron fraction and their impact onsafety analysis

(iii)For new configuration or component, change of Operational Limits and Conditions (OLCs) and its effect on reactor operation

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

2.3.2.3 All the considerations mentioned earlier in sub-section 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 condition**

The predictions required for purposes of core management, in addition to those in sub-section 2.2.4 shall include increase in fissile isotope concentration as a decay product during a shutdown.

2.3.4 **Establishment and implementation of fuelling programmes**

The guidelines for establishment and use of fuelling programmes, in addition to those in 2.2.5 shall include:

(i)Generation of separate fuel scheduling data for each type of fuel

(ii) 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 available on site before any fuel is delivered to site. The Safety Guide on **"Fuel Handling and Storage Systems" (AERB/SG/D24)** provides guidance on design requirements for such facilities.

3.1.2 The fire risks in the new fuel storage areas shall be minimised by avoidance of the 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-D4)**

3.1.3 The plant management shall make arrangements to ensure that a designated person is responsible for the receipt and control of the fuel on site, and that access into the store is limited to authorized personnel.

3.1.4 As soon as fuel has been 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/O-5)** shall be initiated by means of appropriate radiation measurements.

3.1.5 In order to ensure integrity of the fuel elements, the fuel shall be stored and handled only in an approved manner (eg. Horizontal storage).

3.1.6 The 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 fuel bundles.

3.1.7 New fuel, after inspection and identification, should be stored in the designated place before being loaded into the core.

3.1.8 In 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 shall be checked against this identification. The documentation should enable the assembly to be correlated with the records which give information such as enrichment, fuel bundles 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 these persons on the damage that may be acceptable, and a record shall be made on the particular fuel history card of any damage accepted by the examiner. 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 like helium leak test etc., and any scratches on clad surface which may have occurred during transport and handling since previous inspection. Fuel may be inspected on receipt, but in that case appropriate provisions to detect any subsequent damage shall be undertaken prior to insertion into the core.

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/D24)** 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 those 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 the established 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/O-5)** and to prevent damage or contamination to, the fuel.

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

4.0 FUELLING OPERATION

4.1 **Initial fuel loading**

4.1.1 **General**

Initial fuel loading in the reactor may be done manually in dry coolant channels. The fuelling machine vaults shall be maintained as dust free clean rooms. New fuel bundles shall be handled carefully. All personnel working on new fuel loading shall wear clean overalls, shoe covers and hand gloves. Reactor channels shall be thoroughly cleaned, dried and inspected before inserting fuel bundles.

Pre inservice inspection should be carried out to decide the locations of garter springs in the coolant channels before loading the fuel and suitable corrective action should be taken in case required.

4.1.2 **Fuel loading plan**

A detailed initial fuel loading plan shall be made before starting the work. Channel numbers and string locations for different types of bundles like natural uranium bundles, fuel identified for low power zone, special bundles like depleted uranium/thorium etc. shall be clearly identified in the plan. The sequence in which the channels are to be loaded, the direction of loading for each channel, the sequence of loading of other channel components like shielding and sealing plugs etc. shall be indicated in the plan.

4.1.3 **Fuel loading operation**

Each new fuel bundle shall be inspected as per quality assurance requirements and records of past inspection shall be verified. Similarly all channel components shall be inspected and their records verified. A record of such inspection just before installation shall be kept. Extensive care shall be taken to protect the sealing surfaces of channel end fittings and to avoid any damage to them during loading of fuel. The fuel bundles and other channel components shall be loaded in the channel strictly as per the sequence specified in the plan. A record of identification number of each bundle and other component and its location in the reactor shall be made and maintained. The channel components shall be installed using qualified tooling and approved procedures. A record of assembly operations performed and measurements of critical dimensions taken after installation shall be kept as per the procedures.

4.1.4 Loading of any component in the core which is not included in the initial fuel loading plan shall require approval from AERB before they can be loaded into the reactor core. Precaution should be taken to certify immediately before starting of initial fuel loading that all dummy or test assemblies or inspection equipment used for commissioning purpose have been located and removed from the core and no unauthorised equipment, component or material is left in the reactor core.

4.1.5 As prerequisites to ensure that the initial fuel loading is in proper order certain guidelines given in the Appendix B of AERB/SG/0-4 should be followed.

4.2 **Normal refuelling**

4.2.1 **General**

Regular refuelling shall be done as per operating procedures and under the supervision of persons licensed for fuel handling operations. The compliance of such persons and levels of their licensing shall be specified in technical specifications/station policy documents. Refuelling shall be normally done in auto/semiauto mode operation with manual interventions restricted to minimum.

4.2.2 **Loading of fuel and core components**

New fuel shall be identified, inspected and transported for loading into new fuel magazine as per procedures and specified plans. Details such as identification number and position of each bundle in the new fuel magazine tube shall be recorded prior to commencement of refuelling operation. Location of each bundle shall be tracked and recorded all along as it is transferred from new fuel magazine and reaches the coolant channel passing through other fuel handling equipment.

4.2.3 Precaution shall be taken before doing the first refuelling and thereafter whenever any major maintenance is carried out on fuel handling systems to check and certify that all dummy or test bundles, tools etc. used for commissioning or trial runs have been located and removed from any part of the normal Refuelling route so that no unauthorised equipment, component or material inadvertently enters the reactor core. Procedures shall be established to ensure that they are not inadvertently left in the fuel handling route.

4.2.4 Restrictions on number of visits to a hot channel by a cold fuelling machine, if any, shall be taken into consideration and prior approval of Safety Committee shall be taken before exceeding the stipulated number of visits. 4.2.5 If any channel component like shielding plug or sealing plug in the core is replaced, the replacement assembly shall be inspected as per Quality Assurance requirements before insertion in the fuelling machine/coolant channel.

4.2.6 If any item which is not a part of the design covered by the safety report, such as samples of material to be irradiated or inspection head for coolant channel is to be inserted in the core, 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.

4.2.7 Irradiated fuel removed from the reactor should be examined before storage if any physical damage is suspected. Any fuel that is suspected to have failed shall be considered as failed fuel until it is inspected and found to be sound. Failed fuel shall be dealt in a suitable way to reduce contamination of storage facility and to enable meeting of applicable transport requirements for subsequent off-site shipment.

4.3 **Precautions to be taken during refuelling**

4.3.1 Operating procedures for refuelling shall include necessary precautions to be taken to assure safety. Aspects to be considered include component integrity, heat dissipation and radiological protection including shielding.

4.3.2 Such precautions include the following:

(i) Healthiness of fuel handling system shall be ensured before commencement of fuelling operation.

(ii) The commencement of fuelling to be authorized by control room shift charge engineer, who is to be kept informed of the state of refuelling

(iii) The fuelling machine to be operated by licensed persons only and special authorised written procedure to be followed for any abnormal mode of operation; interlocks not to be overridden unless authorised separately on each occasion

(iv) Strict adherence to procedures to be ensured by approved check lists

(v) Checks to be made to ensure that the fuelling machine is properly connected to the correct location; in addition, in the case of bi- directional fuelling designs, that both the loading and unloading machines are aligned to the same channel before clamping (vi) Administrative controls to be devised to supplement design provisions against movement of the fuelling machine while connected to the reactor

(vii) Confirmation to be made about availability of space before pushing the fuel from one subassembly of fuel handling system to another subassembly and also from reactor to fuelling machine and vice versa.

(viii) Alignment of tubes in fuel transfer route and avoiding excessive force during refuelling to prevent strain on fuel bundles.

(ix) Lateral movement of sub-assembly of fuel handling system containing fuel bundle shall only commence after ensuring that fuel will not obstruct the movement of the sub-assemblies. This is to avoid damage to fuel and malfunctioning of the fuel handling system.

(x) Speed of movement of the string of fuel bundles in the channel during an on-power refuelling operation shall be limited to a value such that the rate of change of reactivity due to the movement is well within the capability of the reactor regulating system to compensate.

(xi) A check to be made that the closure plug has been properly replaced before the fuelling machine is disconnected from the channel

(xii) Satisfactory replacement of closure plug to be checked before significant coolant pressure is established after re-fuelling in the depressurised state

(xiii) Controls to 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

(xiv) Dry transfer time shall be limited to ensure temperature rise of the fuel bundle is within acceptable limit. Adequate emergency cooling provision shall be provided for cooling the irradiated fuel bundle in case of exceeding dry transfer time

(xv) Administrative controls to be devised to regulate entry of personnel in the zones where radiation is likely to be high during refuelling operation.

(xvi) It shall be ensured that there is no breach in the reactor building containment isolation during LOCA through the Shuttle Transport Tube.

4.4 Baseline data shall be recorded at the time of commissioning for the following parameters. These parameters shall be observed during regular refuelling and any abnormal or sudden variation shall be examined before taking up refuelling of the next on-power fuelling operations.

i) Differential pressures for various forces of different Rams
ii) Pressure required to operate various hydraulic cylinders in fuel transfer system handling spent fuel.
iii) Time taken for fuel stroke of above mentioned hydraulic cylinders of fuel transfer system.
iv) Time taken for shuttle to reach spent fuel bay from reactor building.
v) Differential pressure/currents drawn by carriage drives.

5.0 IRRADIATED FUEL STORAGE

5.1 In order 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-D24)** and in accordance with written procedures.

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

(iii) Facilitate fuel handling in the pool by maintaining water clarity (removal of particulates). Adequate underwater illumination shall be provided.

5.3 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 authorization is given. The pool crane shall be checked to ensure correct operation prior to the start of fuel handling.

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

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

(i) The pool water level to be maintained between specified levels

(ii) Radiation monitors to be provided and checked periodically 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 the ventilation system to be ensured,

5.6 It is a good practice to maintain sufficient spare capacity in the irradiated fuel storage facility to accommodateone fullcharge of fuel at any giventime.

5.7 In the case of dry storage or storage under liquids other than water, appropriate safety procedures regarding cooling time, surface contamination, monitoring of neutron fields, approved cask design, storage area etc. should 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 to ensure free from damage before insertion into the core. Where appropriate, dimensional and functional checks shall be made to ensure components are in a proper state for their intended use. During handling and installation, checks should be made on undue constraints in order to identify any potential problems.

6.1.2 Each core component as applicable 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 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

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

6.1.5 **Pressure Tube/Coolant Tube removal and replacement**

1. The decontamination activities should be planned properly to bring down the radiation levels for executing the coolant channel replacement programme.

2. Operational sequence for the cutting and transportation of the components should be evolved taking into account availability of all tools needed available to minimise man-rem consumption. If required development activities related to tools should be taken up at appropriate time.

3. The shielding requirements for the defuelling as well as other operations and shipping arrangement for the active core components to be disposed off should be worked out.

6.2 **Surveillance and maintenance of irradiated components**

Programmes shall be established for surveillance and maintenance, where appropriate, of core components during service **(AERB/SG/O-7** and **AERB/SG/O-8)**. Checks should be made for physical changes such as bowing, swelling, corrosion, wear, creep (pressure tube in PHWRs and guide tubes in reactivity devices), 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/SG/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 The 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. Procedures shall be established, using techniques such as check lists, to ensure that the fuel contents of the shipping cask have been loaded as specified.

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

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

7.5 Any previously used cask shall be assumed to contain radioactive substances and be checked for contamination and radiation on arrival at site. If the levels of contamination or radiation are above specified values, an investigation shall be undertaken to discover the cause and ascertain the 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 and suitable measures shall be taken (such as opening under water) to 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 AERB Safety Code
for safety in **"Transport of Radioactive Materials",**
(AERB/SC/TR-1).

8.SURVEILLANCE RELATED TO CORE MANAGEMENT

8.1 The surveillance programme which is related to core management and fuel handling is intended to detect in a timely manner 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 a part of an overall surveillance programme to be formulated and implemented according to the recommendations in **AERB/SG/O-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)

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

(vi) Coolant tube integrity.

9. ADMINISTRATIVE AND ORGANISATIONAL ASPECTS

9.1 The 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 the 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 supplying it, the review and comment requirements, and the approval needed.

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

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

(i) Arrangements for ensuring from the design stage onwards that the Plant Management is provided with the 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 **(IAEASafetySeriesNo.50-SG-QA11).**

(iii) Arrangements for 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/O-7).**

(iv) Arrangements for ensuring that the necessary data and documents (see (i) above) are made available in a timely manner to the Plant Management when modifications (see (iii)above) are introduced.

(v) Arrangements for ensuring that core calculation methods are established and kept up to date in order 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) Arrangements for examination of irradiated fuel for fuel performance evaluation.

(vii) Arrangements for transportation for unirradiated and irradiated fuel and core components.

(viii) Arrangements for storage and handling of unirradiated and irradiated fuel and core components on the plant site.

(ix) Arrangements for the timely collection of information on experience and its dissemination to relevant personnel in the Responsible Organisation and other associated agencies.

9.4 Procedures which shall 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 subsection 2.2.3.1

(v)Actions to be taken by plant operators whenever core parameters are outside the specified limits and conditions for normal operation and actions taken 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/O-7**)

(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 on site of fuel and core components and for the detailed analysis of the performance of 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, 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, test results

(xii) Coolant and moderator inventories, 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 for the fuelling plan and to form the basis for the 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. Composition and distribution of reactivity control devices
5. Predicted criticality condition
6. Insertion, withdrawal and drop times of shutoff rod devices
7. Shutdown system involving liquid poison injection (poison concentration, valve opening time, injection time)
8. Liquid poison addition system (poison concentration and poison addition rates)
9. Moderator dump times, dump valve opening and closing times
10. Power decay curve
11. Startup instrumentation and neutron flux instrumentation overlap requirements
12. Calibration of neutron flux instrumentation and core instrumentation and response time measurements
13. Poison addition system performance
14. Critical moderator level
15. Calibration of reactivity control devices (e.g. regulating or absorber rods)
16. Shutoff system worths
18. Moderator isotopic purity, Moderator system flow rate, temperature rise (includes cooling of calandria support structures, and adjuster rods)
19. Feed water flow and steam flow.

A.I.2. Core conditions

1. Moderator temperature coefficient of reactivity
2. Boron concentration reactivity coefficients
3. Fuel temperature coefficient of reactivity (Doppler)
4. Heat balance
5. Power, flux, and temperature distributions
6. Power coefficient of reactivity
7. Temperature and void coefficients of reactivity
8. Moderator level coefficient of reactivity
9. Maximum linear heat rate or equivalent
10. Major saturation fission product data.

A.I.3 Reactor coolant

1. Temperatures: coolant inlet; coolant outlet; temperature increase between inlet and outlet; coolant outlet temperature distribution (including average temperature of sectors for flux tilt control)
2. Core coolant flow rate (total, required and estimated flow in all channelsandselectedchannelflows), pump characteristics
3. Core coolant pressure
4. Coolant isotopic purity
5. Coolant chemical quality and impurity concentration and composition
6. Fission product activities in primary coolant.

A.I.4. For calculating core thermal power, secondary side parameters (For ex., Feed flow, Feed temperature,reheat drain flow, Reheat drain temperature, Boiler pressures) 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.2 Pressurised Heavy Water Reactors

A.II.2.1 Reactor Simulator

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

1. Three dimensional and at leasttwogroupneutron diffusiontheory calculation
2. Capability to simulate position of all reactivity devices,shutdown devices,moderator level,isotopic purity of coolant or moderator,boron concentration in moderator, power level
3. Capability to simulate refuelling and defuelling operations
4. Capability to assess reactivity worth of reactivity devices and shutdown devices any time during the operation
5. Capability to compare the results of calculation with the measured values in the core, where applicable
6. Output of the code to give: reactivity of the core; fast and thermal neutron flux distributions; distributions of burnup, bundle and channel powers; flux values at incore detector locations; isotopic composition of the fissile materials for in-core as well as discharged fuel; possible violations of OperationalLimits and Conditions (OLCs) on daily basis; comparison of the power distribution with designed reference distribution to assess symmetry in zonal/sector powers, channel power peaking factors etc.

A.II.2.2 Fuelscheduling code

Fuel scheduling code should aim at achieving design discharge burn up while maintaining power distribution within OLCs. The following features are expected in the code:

1. Analysis of channel power distribution to find underpowered zones
2. Analysis of data to enable refuelling such that power peaking does not take place. The data would include the following: Average burnup of bundles in each channels which could be discharged if the channel was to be refuelled with a given refuelling strategy, the full power day at which the channels were refuelled previously etc.
3. Capability to apply bundle power and power ramp criteria while analysing the data to choose channels for refuelling
4. Either generation of data by the code to which guidelines for refuelling can be applied by the operator or the code could have in-built application of the guidelines so that a set of channels in an order of optimality can be made available to the operator.
5. A computer code should exist which will store for each fuel bundle manufacturing and inspection data and bundle power versus burnup. This code could be later used for statistical analysis of fuel failure.

A.II.2.3 Guidelines for refuelling

A typical set of guidelines for selecting a fuel channel are given below.

1. High reactivity gain in the channels fuelled is desirable. Sufficient reactivity is normally maintained by adjusting the fuelling rate to compensate for the reactivity loss due to fuel burnup. When this fuelling rate cannot be maintained, it is necessary to select channels which will produce high reactivity gain upon fuelling.

2. Maximum separation is maintained between channels fuelled at about the same time. Concentrations of freshly fuelled channels would create "hot spots" in the power distribution increasing the probability of fuel defects.

3. The channels having maximum discharge burnup should be given preference. The average burnup of the discharged bundles should correspond to the exit burnup of the corresponding burnup zone.

4. The choice of channels during onset of refuelling should be such that core reaches the equilibrium burnup zone pattern as well as the flux distribution in a smooth manner.

5. Equal number of channels should be refuelled from either direction in each burnup zone so as to minimise the axial tilt in the flux distribution.

6. Flux tilt control capability should not be hampered because of refuelling programme.

   The power produced in different control zones should be kept close to the design values, so that the control elements remain in the operating range. Underpowered zones are fuelled preferentially and overpowered zones are avoided.

7. Refuelling should be such that the maximum channel outlet temperature will be within the Limiting Conditions for Operation (LCO).

8. The bundle power distribution should be kept within the approved bundle power envelope.

9. The channels having failed fuel bundles should be given priority over the other channels.

ANNEXURE-III

Boiling in coolant channels

If boiling is allowed in the maximum powered channels, then the following have to be satisfied:

i) Since channel outlet temperatures of these channels are no longer representative of the power produced in these channels, flux measurements by incore detectors (online flux mapping system) and a validated algorithm to predict channel powers should be required. Systematic comparison of channel powers predicted by Online Flux Mapping System and core follow up codes should be done such that root mean square deviations are within acceptable limits.

ii) The critical powers of channels (Critical power ratio,Minimum critical heat flux ratio) have to be reliably estimated, so that sufficient operational margins are kept to avoid dry-out conditions in the channels during operational transients.

iii) To predict local power peakings, distributed in- core overpower detectors (regional over power detectors) should be installed. The Loss Of Regulation Accident scenarios which may lead to dry out conditions should be analysed in the safety analysis.

iv) The core simulator/fuel management computer programmes should have validated models for simulating voided portions of the channels.

LIST OF PARTICIPANTS

WORKINGGROUP

Dates of Meetings : February 8, 1993
March 18, 30 and 31, 1993
April 20 and 30, 1993

1. Shri H.D. Purandare (Convenor), BARC
2. Shri D.B. Upendra, NPC
3. Dr. R. Srivenkatesan, BARC
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8. Shri A. Ramakrishna (Member-secretary) AERB

Advisory Committee on Codes, Guides and Associated Manuals for Safety in Operation of Nuclear Power Plants constituted by AERB.

Dates of Meeting: July 21, 22, 1994,
May 9, 10, 1995.

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
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Shri R.S. Singh :AERB
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After the review in ACNS (Advisory Committee on Nuclear Safety), following meetings were held on 16th April' 96, 24th April'96 and 11th June' 96 for revising the Guide. These meetings were attended by the following persons.

1. Shri H.D. Purandare (Convenor) BARC
2. Dr.R. Srivenkatesan BARC
3. Shri G. Nageswara Rao NPC
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The document was further reviewed by ACNS on 14th September '96 .
Subsequent to the meeting, the Guide SG/O-10 A was separated incorporating the suggestions of ACNS members.
WG discussed the revised document on 17th February '97.
Part of R2 draft of this Guide was discussed on 10th January, 98 by ACCGASO on 25th October, 97 (mtg.no.39).

REFERENCES

The following documents were referred in this Guide :

Title	No.

I. INTERNATIONAL ATOMIC ENERGY AGENCY Safety Codes and Guides:

1. Code of Practice on Design for Safety of NPPs	IAEA Safety Series No.50-C-D
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 Assemblies	IAEA Safety Series No.50-SG-QA11
5. Safety Aspects of Core Management and Fuel Handling in Nuclear Power Plants	IAEA Safety Series No. 50-SG-O-10

II. ATOMIC EEERGY REGULATORY BOARD 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/O-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 GUIDES ON OPERATION OF NUCLEAR POWER PLANTS

Title	Safety series No.
1. Training and Qualification of Operating Personnel of Nuclear Power Plants	AERB/SG/O-1
2. In-service Inspection for Nuclear Power Plants	AERB/SG/O-2
3. Operational Limits and Conditions for Nuclear Power Plants	AERB/SG/O-3
4. Commissioning for Nuclear Power Plants	AERB/SG/O-4
5. Radiation protection during Operation of Nuclear Power Plants	AERB/SG/O-5
6. Preparedness of the Operating Organisation for emergencies at Nuclear Power Plants	AERB/SG/O-6
7. Maintenance and modifications of Nuclear Power Plants	AERB/SG/O-7
8. Surveillance of items important to safety in NPPs	AERB/SG/O-8
9. Management of Nuclear Power Plants for safe operation	AERB/SG/O-9
10. Core management and fuel handling for Nuclear Power Plants	AERB/SG/O-10

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