GUIDE NO. AERB/NPP-PWR/SG/O-4 C

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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

# COMMISSIONING OF PRESSURISED WATER REACTOR BASED NUCLEAR POWER PLANTS

ATOMIC ENERGY REGULATORY BOARD

**AERB SAFETY GUIDE NO. AERB/NPP-PWR/SG/O-4 C**

# COMMISSIONING OF PRESSURISED WATER REACTOR BASED NUCLEAR POWER PLANTS

**Atomic Energy Regulatory Board**
**Mumbai-400 094**
**India**

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Price:

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# FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers as well as protection of environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety codes, safety standards, related guides and manuals for the purpose. While some of the documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

AERB safety code on 'Nuclear Power Plant Operation' [AERB/NPP/SC/O (Rev.1)] lays down the minimum requirements for safe operation of nuclear power plants to ensure protection of the public, environment and the site personnel from any undue radiological consequences, prevention of accident conditions and mitigation of the consequences of any accidents in the unlikely event of their occurrence. The safety guide on 'Commissioning of Pressurised Water Reactor based Nuclear Power Plants' (AERB/NPP-PWR/SG/O-4C) elaborates the general steps to meet the requirement mentioned in the above code, with respect to commissioning of pressurised water reactor based nuclear power plants in India. While elaborating the requirements stated in the safety code on 'Nuclear Power Plant Operation', this guide provides necessary information to assist personnel and organisations participating in the commissioning of PWR based nuclear power plants.

Consistent with the accepted practice, 'shall' and 'should' are used in the guide to distinguish between a firm requirement and a desirable option respectively. Appendices are integral part of the document, whereas annexures, footnote and bibliography are included to provide information that might be helpful to the user. Approaches for implementation different to those set out in the guide may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

This guide applies only for facilities built after the issue of the document. This document was finalized based on commissioning experience at KK NPP Unit-1.

For aspects not covered in this safety guide, applicable national and international standards, codes and guides, acceptable to AERB should be followed. Non-radiological aspects such as industrial safety and environmental protection are not explicitly considered in this guide. Industrial safety is to be ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

This guide has been prepared by specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Power Corporation of India Limited and other consultants. It has been reviewed by the relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(S. S. Bajaj)
Chairman, AERB

## DEFINITIONS

**Acceptable Limits**

Limits acceptable to the regulatory body for accident condition or potential exposure.

**Acceptance Criteria**

The standard or acceptable value against which the value of a functional or condition indicator is used to assess the ability of a system, structure or component to perform its design function or compliance with stipulated requirements.

**Accident**

An unplanned event resulting in (or having the potential to result in) personal injury or damage to equipment which may or may not cause release of unacceptable quantities of radioactive material or toxic/hazardous chemicals.

**Accident Conditions**

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 as well as beyond design basis accidents.

**Anticipated Operational Occurrences**

An operational process deviating from normal operation, which is expected to occur during the operating lifetime of a facility but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety, nor lead to accident conditions.

**Approval**

A type of regulatory consent issued by the regulatory body to a proposal.

**Atomic Energy Regulatory Board (AERB)**

A national authority designated by the Government of India having the legal authority for issuing regulatory consent for various activities related to the nuclear and radiation facility and to perform safety and regulatory functions, including their enforcement for the protection of site personnel, the public and the environment against undue radiation hazards.

**ATWS-Anticipated Transient Without Scram (ATWS)**

For a nuclear reactor, an accident for which the initiating event is an anticipated operational occurrence for which reactor shutdown is required and it fails.

**Audit**

A documented activity performed to determine by investigation, examination and evaluation of objective evidence, the adequacy of, and adherence to applicable codes, standards, specifications, established procedures, instructions, administrative or operational programmes and other applicable documents, and the effectiveness of their implementation.

**Authorisation**

A type of regulatory consent issued by the regulatory body for all sources, practices and uses involving radioactive materials and radiation generating equipment (see also 'Consent').

**Commencement of Operation of Nuclear Power Plant**

The specific activity/activities in the commissioning phase of a nuclear power plant towards first approach to criticality, starting from fuel loading.

**Commissioning**

The process during which structures, systems and components of a nuclear or radiation facility, on being constructed, are made functional and verified in accordance with design specifications and found to have met the performance criteria.

**Competent Authority**

Any official or authority appointed, approved or recognised by the Government of India for the purpose of the Rules promulgated under the Atomic Energy Act, 1962.

**Consent**

A written permission, issued to the 'consentee' by the regulatory body to perform specified activities related to nuclear and radiation facilities. The types of consents are 'license', 'authorisation', 'registration' and 'approval', and will apply according to the category of the facility, the particular activity and radiation source involved.

**Construction**

The process of manufacturing, testing and assembling the components of a nuclear or radiation facility, the erection of civil works and structures, the installation of components and equipment and the performance of associated tests.

**Decommissioning**

The process by which a nuclear or radiation facility is finally taken out of operation in a manner that provides adequate protection to the health and safety of the workers, the public and the environment.

**Defence-in-Depth**

Provision of multiple levels of protection for ensuring safety of workers, the public or the environment.

**Emergency**

A situation which endangers or is likely to endanger safety of the site personnel, the nuclear/radiation facility or the public and the environment.

**Event**

Occurrence of an unplanned activity or deviations from normalcy. It may be an occurrence or a sequence of related occurrences. Depending on the severity in deviations and consequences, the event may be classified as an anomaly, incident or accident in ascending order.

**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.

**Final Safety Analysis Report (FSAR)**

Safety analysis report submitted to the regulatory body for obtaining consent for operation of a nuclear/radiation facility.

**Full Power**

The rated thermal power of the reactor, i.e. the gross fission power as established by the station heat balance, using approved methodology.

**Inspection**

Quality control actions, which by means of state of examining, 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.

**License**

A type of regulatory consent, granted by the regulatory body for all sources, practices and uses for nuclear facilities involving the nuclear fuel cycle and also certain categories of radiation facilities. It also means authority given by the regulatory body to a person to operate the above said facilities.

**Normal Operation**

Operation of a plant or equipment within specified operational limits and conditions. In case of a nuclear power plant, this includes, start-up, power operation, shutting down, shutdown state, maintenance, testing and refueling.

**Nuclear Power Plant (NPP)**

A nuclear reactor or a group of reactors together with all the associated structures, systems, equipment and components necessary for safe generation of electricity.

**Nuclear 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.

**Operation**

All activities following and prior to commissioning performed to achieve, in a safe manner, the purpose for which a nuclear/radiation facility is constructed, including maintenance.

**Operational Limits and Conditions (OLC)**

Limits on plant parameters and a 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 nuclear/radiation facility (see also 'Technical Specifications for Operation').

**Operational States**

The states defined under 'normal operation' and 'anticipated operational occurrences'.

**Plant Management**

Members of the site personnel who have been delegated responsibility and authority by the responsible organisation/operating organisation for directing the operation of the plant.

**Preliminary Safety Analysis Report (PSAR)**

Safety analysis report submitted to regulatory body for obtaining consent for construction.

**Prescribed Limits**

Limits established or accepted by the regulatory body.

**Protection System**

A part of safety 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 support features, involved in generating the signals associated with the safety tasks.

**Qualified Person**

An individual who, by virtue of certification by appropriate authorities and through experience, is duly recognised as having expertise in a relevant field of specialisation like quality assurance, radiation protection, plant operation, fire safety or any relevant engineering or safety specialty.

**Quality Assurance (QA)**

Planned and systematic actions necessary to provide the confidence that an item or service will satisfy given requirements for quality.

**Records**

Documents, which furnish objective evidence of the quality of items and activities affecting quality. They include logging of events and other measurements.

**Regulatory Body**

(See 'Atomic Energy Regulatory Board').

**Regulatory Consent**

(See 'Consent').

**Reliability**

The probability that a structure, system, component or facility will perform its intended (specified) function satisfactorily for a specified period under specified conditions.

**Responsible Organisation**

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

**Safety Actuation System**

A part of safety system, which encompasses all the equipment, required to accomplish the required safety action when initiated by the protection system.

**Safety Analysis Report (SAR)**

A document, provided by the applicant/consentee to the regulatory body, containing information concerning the nuclear or radiation facility, its design, accident analysis and provisions to minimise the risk to the public, the site personnel and the environment.

**Safety Culture**

The assembly of characteristics and attitudes in organisations and individuals which establishes that as an overriding priority, the protection and safety issues receive the attention warranted by their significance.

**Safety Support System**

Part of safety systems which encompasses all equipment that provide services, such as cooling, lubrication and energy supply (pneumatic or electric) required by the protection system and safety actuation systems.

**Safety System**

System important to safety and provided to assure that under anticipated operational occurrences and accident conditions, the safe shutdown of the reactor followed by heat removal from the core and containment of any radioactivity, is satisfactorily achieved. (Examples of such systems are shutdown systems, emergency core cooling system and containment isolation system).

**SCRAM System**

The system used for rapid shutdown of a nuclear reactor usually by either automatic or manual insertion of control rods.

**Severe Accident**

Nuclear facility conditions beyond those of the design basis accidents causing significant core degradation.

**Site Personnel**

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

**Technical Specifications for Operation**

A document approved by the regulatory body, covering the operational limits and conditions, surveillance and administrative control requirements for safe operation of the nuclear or radiation facility. It is also called ‘operational limits and conditions’.

**Testing (QA)**

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.

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# 1. INTRODUCTION

## 1.1 General

1.1.1 Safety code of Atomic Energy Regulatory Board (AERB) on 'Nuclear Power Plant Operation' [AERB/NPP/SC/O (Rev. 1)] requires that the commissioning programme shall assure that, after construction, the nuclear power plant (NPP) is made operational in a systematic, informative and safe manner. The programme shall verify that the performance criteria, design intent and quality assurance (QA) requirements are satisfied. It shall demonstrate that the plant can be operated in a safe manner through integrated testing of the plant system(s).

1.1.2 Carefully planned and executed commissioning is essential for the subsequent safe operation of the plant. Accordingly, a detailed programme of commissioning of various systems including tests is prepared, and the responsibility for executing and reporting on the various parts of the commissioning programme is clearly defined. The commissioning programme needs approval of AERB. Close liaison should be maintained between AERB, responsible organisation and the plant management throughout the development and implementation of the commissioning programme.

## 1.2 Objective

This guide elaborates the general steps to meet the requirements of the safety code on 'Nuclear Power Plant Operation' (AERB/NPP/SC/O R-1) during commissioning of Pressurised Water Reactor based Nuclear Power Plants.

## 1.3 Scope

1.3.1 This guide is applicable to land based stationary nuclear power plants of pressurised water reactor (PWR) type and addresses the commissioning aspects for subsequent safe operation.

1.3.2 This safety guide can be made use of, when a nuclear power plant is to be restarted after an extended shutdown period or extensive modifications have been made to an existing nuclear power plant.

# 2. ORGANISATION, RESPONSIBILITIES AND AUDIT

## 2.1 Organisation

Various organisations involved in the commissioning and their role in commissioning are given below. The details of responsibilities are covered in subsequent sections. A typical organisation chart during commissioning is given in Fig.1.

2.1.1 Responsible organisation should be the overall controlling and coordinating authority to oversee satisfactory completion of all commissioning activities.

2.1.2 Plant management should be designated by the responsible organisation for construction, commissioning and operation of the Nuclear Power Plant.

2.1.3 Principal activities of construction and installation of the plant should be entrusted to the construction group. The construction group should ensure that the installation has been completed as per design.

2.1.4 Commissioning and operation of the plant should be entrusted to the commissioning group and operation group of plant management respectively.

2.1.5 A commissioning group leader should be appointed well in advance of actual commencement of commissioning activity. He should have adequate experience of commissioning and operation of nuclear power plants.

2.1.6 The commissioning group should have sub-groups with adequate manpower and identified team leaders. The organization chart should be made available to construction and operations groups and to various commissioning sub groups to ensure effective work coordination.

2.1.7 There should be a planning and scheduling unit for the project to monitor the progress of commissioning including the issuance of commissioning reports, transfer certificates of systems and other related aspects. Progress of the project is to be reported periodically to the plant management, responsible organisation and AERB.

2.1.8 Designers, manufactures, quality assurance personnel, contractors and consultants should also participate in the commissioning programme, wherever required.

2.1.9 All organisations involved in the commissioning process should work in a coherent manner towards achieving and sustaining high level of safety culture.

## 2.2 Responsibilities

### *2.2.1 Responsible Organisation*

Responsible Organization is overall responsible for design, siting, construction, commissioning, operation and de-commissioning of the nuclear power plant. Responsibilities of responsible organisation are as follows:

(i) To review, coordinate and control the activities of commissioning and operation of nuclear power plant in an effective and safe manner

(ii) To ensure availability of adequate number of trained, experienced, qualified and, where required, authorised/licensed personnel in commissioning and operation of nuclear power plant

(iii) To ensure that the commissioning procedures are prepared, reviewed and approved by personnel with appropriate technical background and experience

(iv) To arrange for the required submissions to AERB and obtain approval at the agreed phases/sub-phases and to comply with the requirements of AERB. The submissions should be according to the requirements stated in the section 3.2-'Information needed for issue of consents' (as applicable for PWR) of 'Consenting Process for Nuclear Power Plants and Research Reactors' (AERB/NPP&RR/SG/G-1) with inputs from designer

(v) To establish the procedures for ensuring coordination taking into account the views and experience of members of the construction, commissioning and operations groups as well as other participants of commissioning such as the designers, manufacturers, consultants and quality assurance personnel.

The essential tasks in achieving the necessary coordination are as follows:

(a) To review the commissioning programme and have it issued after approval

(b) To identify and monitor the transfer of responsibilities from construction group to commissioning group through plant management

(c) To monitor the implementation of the commissioning programme

(d) To ensure compliance with safety aspects of proposed changes in design

(e) To ensure prompt resolution of various issues arising during commissioning needing coordination of various agencies

(f) To maintain liaison with AERB.

(vi) To ensure the participation of designers, manufacturers and supporting technical organisations in the commissioning activities as required.

2.2.2 *Plant Management*

Plant management is responsible for construction, commissioning and operation of the plant. Plant management directly interacts with the AERB during commissioning of the plant (Figure-1). Responsibilities of plant management are as follows:

(i) To ensure quality assurance during commissioning

(ii) To ensure industrial and fire safety during commissioning

(iii) To ensure availability of physical protection system and nuclear security measures, as appropriate, to the stage of commissioning

(iv) To conduct internal audit of commissioning activities

(v) To ensure that appropriate regulatory and statutory clearances are obtained before/during all project stages including before start of commissioning,

(vi) To ensure availability of adequate and appropriate manpower and to make arrangement with respect to manpower utilisation between the construction, commissioning and operation groups and to ensure that the division of responsibilities remain clearly identified during overlapping of construction, commissioning and operation

(vii) To plan, in advance, commissioning programmes with detailed test sequences, time schedules, manpower and material requirements taking into consideration commissioning experience of earlier NPPs

(viii) To ensure participation and coordination between the members of construction group, commissioning group, operation group, quality assurance group and representatives of designers, manufacturers, consultants etc.

(ix) To submit applications along with required documents seeking clearances from AERB for pre-identified commissioning sub-phases and to maintain liaison with AERB

(x) To ensure that the following documents are available:

(a) QA programme for commissioning

(b) Operational flow sheets, electrical diagrams, process and instrument diagrams, as built drawings

(c) Approved commissioning procedures

(d) Operating and maintenance instructions and procedures, training manuals

(e) Technical specifications for operation as approved by AERB

(f) Radiation protection procedures, radiation emergency procedures, station protection code and station norms

(g) Formats for commissioning reports

(h) Test results, commissioning procedures and reports and other relevant documents

(i) System transfer documents to handover system to operation group

(j) Approved emergency operating procedures (EOPs).

(xi) To establish and implement procedures and criteria for sequential transfer of responsibility for structures, systems and components and related documents from construction to commissioning group and from commissioning to operation group

(xii) To establish a procedure for analysing and reporting the events that occurred during commissioning, as feed back to the designers and operation group for necessary corrective action

(xiii) To establish a procedure for design changes when specified design criteria are not met or when they fall short, as a part of configuration management

(xiv) To ensure that operation personnel gain commissioning experience

(xv) To ensure that all phases of commissioning programme are satisfactorily completed and documented.

*2.2.3 Construction Group*

Responsibilities of Construction Group are as follows:

(i) To ensure that the installation of structures, systems and components (SSC) has been completed in accordance with design requirements and specifications

(ii) To make suitable arrangements for pre and post installation preservation of SSC and their surveillance and maintenance, as necessary

(iii) To generate and provide to commissioning group/operations group: baseline data, results of pre service inspection (PSI), as-built installation documentation, test certificates for tests done during manufacturing as well as during installation periods including site tests such as air hold tests and hydrostatic tests highlighting design changes, non-conformances and concessions

(iv) To ensure normalisation of systems and components after required test/inspection

(v) To establish and implement foreign material exclusion programme during construction and ensure exclusion of foreign material from the system before handing over to commissioning group

(vi) To transfer systems to commissioning group and issue construction completion certificates (CCC) to the commissioning group

(viii) To correct the construction deficiencies detected during commissioning and to raise design concession request (DCR) as per normal procedure for deficiencies which cannot be corrected

2.2.4 *Commissioning Group*

Responsibilities of commissioning group are as follows:

(i) To confirm that structures, systems and components are tested in a safe, systematic, efficient and informative manner and are ready for safe operation

(ii) To verify that the plant has been properly designed and constructed

(iii) To establish methodology for the preparation, review and approval of commissioning procedures, test procedures, emergency operating procedures and other procedures and prepare these procedures, taking input from the system designers and manufacturers, as appropriate

(iv) To ensure that the commissioning procedures comply with the appropriate radiological safety rules, relevant technical specifications for operation and applicable rules for industrial and fire safety

(v) To ensure the consistency between design requirements, as built drawings, physical configuration of SSC and are coded for proper identification

(vi) To establish procedure for controlling temporary changes to plant and equipment

(vii) To establish procedure for controlling changes in approved commissioning procedure

(viii) To ensure that procedures are in place to control the calibration of testing equipment

(ix) To establish procedures for analysing the results of commissioning tests and for producing commissioning reports and test certificates, and to prepare and issue these reports/certificates

(x) To make suitable arrangements for maintaining commissioned systems/components in a safe manner

(xi) To ensure that the systems are commissioned to meet their design requirement and to confirm that the written operating procedures are adequate

(xii) To implement all tests in the commissioning programme, including repeat testing of the systems that have been commissioned initially as partially installed

(xiii) To analyse/assess that the plant performance is within the limits specified in technical specifications for operation including aspects of radiological protection

(xiv) To report to the plant management, any deficiency detected during commissioning to facilitate review and corrective actions, as required

(xv) To provide information for updating operational flow sheets, operating and maintenance instructions and procedures based on commissioning experience

(xvi) To collate baseline information during commissioning for future reference

(xvii) To train operation group staff including persons from operation, maintenance, technical services and other related services

(xviii) To conduct acceptance or capability or guarantee test, review the test result, modify SSC or test procedure, if required , re-test and accept

(xix) To operate the plants systems in integrated manner and tune the systems, as necessary

(xx) To transfer the commissioned systems and/or plant to the operation group, using document like system transfer document.

2.2.5 *Operation Group*

Responsibilities of operation group are as follows:

(i) To operate the plant as per 'technical specifications for operation' as relevant during commissioning phase and in accordance with commissioning programme

(ii) To participate in the commissioning activities to become familiar with the plant and facilities, starting from the commissioning phase and to train manpower.

(iii) To ensure that the systems accepted from commissioning group comply with specified performance, design and safety requirements.

(iv) To accept the responsibility of transferred systems from commissioning group.

2.2.6 *Other Participants[1] in the Commissioning Activities*

Responsibilities of other participants in the commissioning activities are as follows:

(i) To provide technical support and share relevant experience from plants/systems already commissioned

(ii) To provide independent safety assessment, as necessary

(iii) To provide feedback about the engineering changes made in this unit which need to be implemented in the units under design, construction, commissioning or operation as applicable.

**2.3 Interaction with AERB**

2.3.1 Responsible organisation and plant management should maintain close liaison with AERB throughout the development and implementation of commissioning programme.

2.3.2 The responsible organisation and plant management should identify representatives to interact with AERB and the respective organisations. The representatives will be the hub of information flow between the respective organisations and also with AERB during all phases of commissioning till regular operation starts.

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1 Other participants includes designers, manufacturers, consultants, contractors and technical support organisation

2.3.3 During commissioning of the plant, plant management should submit the required documents and information for review and assessment of the commissioning process as agreed in the commissioning programme. Any major deviation from design and event occurred at the plant site should be reported to AERB as per significant event/change reporting procedure for nuclear projects.

**2.4 Audits**

2.4.1 The responsible organisation should arrange for audits to verify compliance with commissioning programme by periodic reviews of documents, records and field visits. The audit should be performed by a team of experienced personnel not having direct responsibilities in the areas being audited.

2.4.2 The plant management should take necessary action to correct deficiencies revealed during the audits.

# 3. COMMISSIONING PROGRAMME

## 3.1 General

3.1.1 A detailed programme of commissioning activities should be prepared and responsibilities for implementing and reporting on the various parts of the commissioning programme should be clearly defined.

3.1.2 The commissioning programme should identify all the tests and related necessary activities which are required to be performed during commissioning in all the systems to demonstrate that the plant has been properly designed and constructed and can be operated safely.

3.1.3 The results of commissioning should demonstrate that the design intents have been met and confirm the assumptions made in the safety analysis report.

3.1.4 The commissioning should cover all the activities to be performed on structures, systems and components to bring them to an operating mode. It should be established that adequate margins exist between the design, safety requirements and the actual performance.

3.1.5 The commissioning programme should clearly indicate the regulatory hold points.

3.1.6 Adequate provision should be made for the allocation of responsibilities for safety and nuclear security at different phases/sub-phases of the commissioning programme.

3.1.7 The commissioning programme should include:

(i) Tests which aim at the verification of each functional system including its overall performance in an integrated manner

(ii) Specific tests performed on the prototype plant of a series in order to validate new concepts. Similar tests on the other plants of the series are to be done for confirming test results obtained earlier e.g. natural circulation confirmation during SBO

(iii) Tests aimed at acquiring data to validate computer code used for the safety analysis and to confirm the validity of the limiting safety system settings.

3.1.8 During commissioning, normal operating procedure including those for surveillance and performance tests should be used to validate the applicability of the procedures. Emergency operating procedures (EOP) should also be validated, to the extent possible.

3.1.9 Job hazard identification and risk analysis should be performed prior to carrying out any commissioning activity and outcome/results of such exercise should be appropriately incorporated in the test procedures/ commissioning procedures.

**3.2 Main Aspects of Commissioning Programme**

3.2.1 The commissioning programme should be prepared in accordance with the quality assurance programme for commissioning. The quality assurance programme should be developed complying the requirements stated in AERB safety guide on 'Quality Assurance during Commissioning and Operation of Nuclear Power Plant' (AERB/SG/QA-5).

3.2.2 The commissioning programme should assure that the plant will be commissioned in a safe, systematic, efficient and auditable manner.

3.2.3 The commissioning programme should be prepared so as to enable the objectives and methods of testing to be readily understood by all concerned and to allow control and coordination by management.

3.2.4 For multi unit plants, separate commissioning programme should be prepared for each unit.

3.2.5 The commissioning programme should be divided into phases and sub-phases whose number and size will depend upon safety, technical and administrative requirements. The programme should show the planned duration of the activities and their interrelationships.

3.2.6 The commissioning programme should be structured to meet the following requirements:

(i) Commissioning is performed in a systematic sequence so that the plant is progressively subjected from less onerous conditions to more onerous conditions,

(ii) Regulatory hold points and specified tests to be witnessed (as decided by AERB) by AERB are identified, and

(iii) Facilitate training of operation and maintenance personnel.

3.2.7 The commissioning programme should provide a framework for scheduling of tests and availability of suitable personnel, equipment and material at the proper time.

3.2.8 The commissioning programme should take into account the lead time required for review of documents by AERB as given in AERB safety guide 'Consenting Process for Nuclear Power Plants and Research Reactors' (AERB/NPP&RR/ SG/G-1).

3.2.9 The commissioning programme should also meet the requirements of applicable acts and rules of other statutory bodies (non-nuclear).

3.2.10 Security measures should be in place for safe storage of fuel, prior to arrival of fuel at site, as per regulatory guidelines issued by AERB.

3.2.11 Responsible organisation should review and approve the commissioning programme.

3.2.12 The commissioning programme should be submitted to AERB for review and acceptance.

**3.3 Phases of Commissioning**

3.3.1 The commissioning programme of a nuclear power plant should be divided into phases and sub-phases. Typical phases are as follows:

(i) Phase-A : Pre-operational tests

(ii) Phase-B : Initial fuel loading, pre-critical tests, first approach to criticality (FAC) and low power tests

(iii) Phase-C : Power ascension tests.

The sub-phases are elaborated in section 5.0 of this guide.

3.3.2 Each phase/sub-phase should include the actions/tests required to be performed as prerequisites for the succeeding phase/sub-phase.

3.3.3 Review of the commissioning results of each phase/sub-phase should be completed before approaching the next phase/sub-phase.

**3.4 Regulatory Clearance**

3.4.1 Plant management should obtain concurrence of AERB for the commissioning programme.

3.4.2 Regulatory reviews and clearances are necessary for the following phases/ sub-phases (for typical design of PWR) of commissioning:

(i) Hot run and related commissioning tests

(ii) Initial fuel loading, pre-critical tests[2]

(iii) First approach to criticality and low power physics experiments

(iv) Power ascension in stages (typically at 50 %, 90 % and 100 % FP)

(v) License for regular operation.

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2 The time interval between initial fuel loading and first approach to criticality should be as short as possible.

3.4.3 For each phase/sub-phase of commissioning where regulatory clearance is required, application seeking clearance (s) should be submitted to AERB by the plant management along with details of the tests to be conducted, expected test results and acceptance criteria, test results of the previous phase/sub-phase (if not already submitted) and status of reactor plant systems.

3.4.4 Regulatory review and clearance is required prior to receipt and storage of fresh fuel at site.

# 4. DOCUMENTS

## 4.1 General

4.1.1 Commissioning documents should describe the proposed commissioning activities; provide data and results and their evaluation. These should provide assurance that the activities have been correctly performed.

4.1.2 Main supporting documents of commissioning are regulatory documents, design documents, construction documents, equipment manufacturer's instruction etc.

4.1.3 Commissioning and its supporting documents should provide:

(i) assurance to the plant management that commissioning is proceeding in accordance with all stated requirements,

(ii) continuity in the commissioning activity and means for continuous updating of documents to facilitate the execution of phase/sub-phase reviews,

(iii) evidence that the design requirements have been verified or appropriate changes/modifications are implemented to meet the design requirements,

(iv) assurance that the regulatory requirements are satisfied and

(v) records, that are needed to be available throughout the life of the plant.

4.1.4 Commissioning and its supporting document should include the following:

(i) Commissioning programme, schedules, procedures and reports

(ii) Construction completion certificates, data collection sheets, standard test sheets, summary test reports, records of deviations and deficiencies noticed during commissioning and corrective actions taken, final test reports, test completion certificates, system transfer certificates, phase/sub-phase completion certificates

(iii) Documents providing input data and additional information for commissioning such as : vendor's specifications, design and safety analysis reports and subsequent changes thereof, regulatory requirements, and other applicable statutory documents, pre service inspection (PSI) and in service inspection (ISI) documents

(iv) Documents to be verified during commissioning such as: operational limits and conditions, operating and maintenance instructions and procedures, and other documents prepared for operation (typical list of operational documents to be verified during commissioning is attached as Annexure- I)

(v) Other documents relevant to commissioning such as: record systems for fuel management and other nuclear materials, industrial safety procedures for safety of personnel, radiological protection procedures and associated records.

4.1.5 Preliminary safety analysis report (PSAR), duly revised after design review, should be submitted to AERB well before commencement of the commissioning activities. Commissioning schedule, network diagram-level II (containing elaborate commissioning activities) and the list of commissioning procedures for all the systems and equipments should also be submitted to AERB.

4.1.6 Commissioning procedures of safety systems, safety related systems, engineered safety features and other important commissioning procedures as identified by AERB should be submitted for review. Approved and updated commissioning procedures should be used for commissioning of systems.

4.1.7 For maintenance (preventive or predictive maintenance, reliability centred maintenance and condition monitoring) and life management of NPP, collection of PSI data for subsequent in service inspections and baseline data for monitoring performance of SSC are important.

Details of data to be collected during PSI should be as per the approved document for conducting PSI and ISI for the NPP. During preparation of PSI/ISI documents AERB guide on ‘In service Inspection of Nuclear Power Plants’ (AERB/NPP/SG/O-2) should be taken into consideration.

4.1.8 Collection of baseline data for SSC should be started from the stage of manufacturing. It should include the tests conducted at manufacturer’s shop, construction and erection, tests carried out during construction and erection and tests carried out during commissioning and initial operation. Utility should identify important parameters to be monitored in the above mentioned stages for life cycle management and incorporate these parameters in appropriate test procedures. These data should be recorded and preserved permanently. Typical list of baseline data to be collected is available in Annexure II. Annexure IV, V and VI mention baseline data to be collected during tests at various stages of commissioning.

## 4.2 Applicable Codes and Guides

All applicable safety codes and guides including those required for industrial and fire safety should be mentioned in the relevant commissioning document.

## 4.3 Application for Different Phases/Sub-phases

Application for different phases/sub-phases of commissioning should be submitted to AERB. The submissions to be made along with application should contain, but not limited to the following:

(i) Status of systems

(ii) Pre requisites to be fulfilled

(iii) Relevant commissioning test results of the previous phase/sub-phase of commissioning, comparison with acceptance criteria, designers evaluation and their review report

(iv) Commissioning procedures for important integrated tests to be carried out during the phase/sub-phase for which application is submitted (if not already submitted and reviewed)

(v) Non-conformance to the requirements of codes and guides, if any, along with proper justification

(vi) Expected results/acceptance criteria of the phase/sub-phase for which application is submitted.

## 4.4 Post Commissioning Documents and Review

4.4.1 After completion of each phase/sub-phase of commissioning as per approved commissioning programme, commissioning reports should be prepared. (also see section 5.8.4)

4.4.2 The commissioning report should contain, but not limited to the following:

(i) Summary reports

(ii) Final reports

(iii) Records of deviation and deficiencies noticed during commissioning and corrective actions taken

(iv) Test completion certificates

(v) Phase/sub-phase completion certificates (wherever applicable)

(vi) System transfer certificates

(vii) QA certifications.

4.4.3 All commissioning reports should be reviewed by plant management and designers. Review should verify that all activities have been correctly performed and results verify the design intent.

## 4.5 Document Control

Control of commissioning document should be according to the quality assurance programme of the utility. Control of document should meet the requirements of codes and guides of AERB (AERB/SC/QA and AERB/NPP/SG/QA-9).

# 5. IMPLEMENTATION OF COMMISSIONING PROGRAMME

## 5.1 General

5.1.1 Commissioning tests should be comprehensive to establish that the plant can operate in all modes for which it has been designed to operate. However, commissioning test, which has not been analysed or if it falls outside the range of assumptions made for analysing postulated events or accidents in the safety analysis report, or it has potential to damage the plant or jeopardise safety, should not be conducted. Plant operating mode or plant configuration which could damage the plant or jeopardise safety should not be established.

5.1.2 In determining the sequence of commissioning tests, following points should be considered.

(i) Priority should be given for commissioning of support systems like service water system, compressed air system, electrical power supply system etc, which will be required for commissioning of other systems.

(ii) Certain systems should be operational to ensure that other systems can be tested and commissioned, without jeopardising personnel, plant or nuclear safety e.g. fire water system should be commissioned before commissioning of transformers requiring deluge for fire safety.

(iii) Commissioning tests which are to be performed in a phase or sub-phase may be grouped and completed together, to the extent practicable.

(iv) Sequence of commissioning tests within a phase/sub-phase should be given in the chronological order in which they are expected to be performed.

5.1.3 If some of the structures, systems and components are common to more than one unit, commissioning tests should be conducted to provide assurance that the specified performance requirements can meet the design requirement of each unit.

5.1.4 Special provision should be made to ensure that the safety of a unit already in operation is not jeopardised during the commissioning of the other unit. Such provisions should include conducting a hazard assessment and obtaining the prior approval of AERB and specific written approval from the plant management responsible for the operating unit.

5.1.5 All transients/malfunctions which are recommended by the plant designers to be simulated/performed during commissioning should be carried out after making a detail plan and procedures towards ensuring safety of plant and personnel.

No transient or malfunction test should be carried out without analysing the event by the designers. If analysis is not carried out previously, then the event should be analysed and simulated in simulator (if possible). Relevant important points to be followed during test should be included in the detailed test plan.

Other tests including transients which are simulated on training simulator should also be conducted (to the extent possible) to verify the analytical result.

5.1.6 The demonstration of the capability of the systems and components to withstand failure/malfunctions that has been experienced previously and may occur over the expected plant lifetime should be considered (typical list of hazards and malfunctions is attached as Annexure-III).

5.1.7 To the extent practicable, the commissioning tests should be of sufficient duration to allow the systems and components under test to reach their equilibrium conditions.

5.1.8 The commissioning tests on the systems, which are First of A Kind (FOAK) should be started at an early stage and performed in applicable phase/sub-phase at which the performance can be evaluated optimally.

5.1.9 Computer based systems (CBS) important to safety should be commissioned and validated in-situ after completion of the independent verification and validation (IV&V) of the software by the utility.

## 5.2 Commissioning Tests Requirements and Acceptance Criteria

Commissioning tests to be carried out at various phases/sub-phases of commissioning are as follows (typical pre-operational checks are given in Annexure-IV and typical commissioning activity diagram for various phases is given in Fig.2):

### *5.2.1 Phase A -Pre-operational Tests*

5.2.1.1 Before the commencement of the commissioning test of any structure, system or component, following steps should be ensured:

(i) Construction activities associated with the system, including quality assurance checks and documentation should be completed and reviewed.

(ii) The equipment is ready for commissioning as per prerequisites mentioned in the applicable commissioning procedure.

(iii) Test equipment and instruments to be used during commissioning are appropriate and operable, properly calibrated and response times are within acceptable limits.

5.2.1.2 If any additional commissioning test is to be carried out based on input obtained from construction group, then the same should be performed.

5.2.1.3 Commissioning programme should ensure proper sequence of commissioning of electrical systems, instrumentation and control systems, compressed air systems, cooling water systems, fire protection systems and other service systems.

5.2.1.4 The phase of the pre-operational tests may be divided into the following sub-phases:

(i) Functional checks (refer annexure-IV)

(ii) Cold run

(iii) Hot run

5.2.1.5 Required pre-service inspections should be carried out and other data should be collected during and/or at the end of these sub-phases.

**5.2.2 Cold Run**

5.2.2.1 Cold run includes the initial start up of fluid systems and support systems. The objective of this sub-phase is to obtain initial operational data, ensure compatibility with interfacing systems and verify functional performance of these systems. The tests should include pressure testing of the primary and secondary systems.

5.2.2.2 If, the required pressure test was not carried out by manufacturer or construction group, it should be carried out as part of the commissioning programme in this sub-phase.

**5.2.3 Hot Run**

5.2.3.1 Hot run should be undertaken to verify the conformance of systems with specified requirements. The commissioning tests during this phase should simulate plant operating conditions, as far as practicable, including anticipated operational occurrences at typical temperatures, pressures and flow rates.

5.2.3.2 The duration of hot run should be such that a steady state operating condition is achieved.

5.2.3.3 The commissioning tests should verify the effectiveness of thermal insulations and heat removal systems. Initial checking of vibration of pipelines and rotating equipment, clearances and provisions made for accommodating the thermal expansion of structures, systems and components should be done. The operation of equipment and instruments at high temperature should be verified. The relevant operating scheme should be confirmed. Process logic checks should be carried out.

**5.2.4 Phase B -Initial Fuel Loading and Pre-Critical Tests**

5.2.4.1 The purpose of the sub-phase of initial fuel loading and sub-critical tests is to ensure that the fuel is loaded into the reactor core safely in accordance with the pre-calculated loading pattern. The reactor should remain sub-critical with adequate margin. Prerequisites for fuel loading are given in Appendix-A.

5.2.4.2 Initial fuel loading is considered as commencement of operation. The 'Technical Specifications for Operation' is applicable from this phase of commissioning.

5.2.4.3 Before loading the fuel in the core, access control, radiation protection and nuclear security measures should be ensured.

5.2.4.4 Checks on coolant flow rates, performance of various instruments, reactor protection system, reactivity control mechanisms, automatic control rod insertion and other important features of the primary circuit should be conducted with the core loaded and the reactor maintained in a sub critical condition.

5.2.4.5 Continuous monitoring of neutron flux should be ensured.

5.2.4.6 Appropriate trip limits of the neutron flux channel for the reactor protection system should be set to a conservative level from this phase onwards.

5.2.4.7 Adequate training of control room personnel for first approach to criticality should be ensured.

**5.2.5 First Approach to Criticality and Low Power Tests**

5.2.5.1 During this sub-phase, the criticality of fresh core is achieved for the first time. Therefore all precautions shall be taken to prevent reactivity excursion. It is to be ensured that the reactor protection system and shutdown devices are tested; results are satisfactorily and are poised. The subsequent low power tests (details of the tests are given in Annexure-V) should be carried out to confirm that the following requirements are fulfilled.

(i) The performance of the reactor core is commensurate with predictions made in the core design.

(ii) The reactor core status is ensured for operation at higher power levels and the characteristics of the reactor core coolant, reactivity control systems and shielding are in accordance with design predictions.

(iii) The reactor physics parameters (including worth of reactivity mechanism and different coefficients) are in accordance with predictions made in the design.

(iv) In order to permit power testing, assurance should first be obtained on the basis of the information gained from these tests that there is no significant discrepancy between measured values of reactor physics parameters and other parameters used in the safety analysis.

5.2.5.2 The reactor power levels should be the lowest achievable that ensure reliable and stable measurements and which enable the conditions required to perform the specified tests.

5.2.5.3 Radiological surveys and functional checks of radiation monitoring equipment should be carried out.

5.2.5.4 In these tests, the trip limits of the neutron flux channel for the reactor protection system should be set to a conservative level. Special start-up instrumentation should be used, if necessary.

**5.2.6 Phase-C Power Tests**

5.2.6.1 A comprehensive range of power tests (details of the tests are given in Annexure-VI) should be conducted to confirm that the plant can be operated in accordance with the design intent and that the plant can continue to be operated in a safe manner. This sub-phase should in general be limited to those tests, which can be carried out only at power.

5.2.6.2 This phase consists of a step by step approach to full power and full power tests. Typical sub-phase may be with minimum power required for stable operation of turbine-generator, 50%, 75%, 90% and 100% of full power.

5.2.6.3 Commissioning tests should be planned to demonstrate to the extent practicable that the plant operates in accordance with the design both in steady state conditions and during and after anticipated operational occurrences, including reactor trips, transients in heat transport system (primary, secondary and tertiary) and load rejections initiated at appropriate power levels as envisaged in preliminary safety analysis report.

5.2.6.4 A review should be carried out at the end of each sub-phase to confirm whether the operational limits and conditions are adequate as demonstrated by commissioning test. The review should identify necessary constraints on the operation of the plant.

**5.2.7 Acceptance Criteria**

Acceptance criteria of all the tests should be as per preliminary safety analysis report and/or as per the approved commissioning procedures. The structures, systems and components should meet the design intent. The tests results should meet the acceptance criteria as specified in the relevant documents.

## 5.3 Commissioning Test Procedures

5.3.1 Commissioning tests should be performed in accordance with approved procedures. The procedures should describe in detail how each equipment, system or component will be commissioned. The level of review should reflect the importance to safety of the system and the nature of the test. The preparation of test procedures, their verification and approval, should be defined by an administrative procedure.

5.3.2 Special attentions should be paid while preparing and reviewing commissioning procedures for equipment or systems that are first of a kind (FOAK). The commissioning procedures should indicate the acceptance criteria of system performance.

5.3.3 Identified procedures will be reviewed by AERB. The designer's comments on these procedures should be made available to review committees.

5.3.4 The procedures should follow normal plant operating procedures to the extent practicable, so as to verify them. If necessary, the normal operating procedures are to be amended and approved for use based on commissioning experience.

5.3.5 The procedures should state any necessary deviations from the design or normal operating configurations. Procedures should also state the necessary checks to be undertaken to ensure that such changes are made correctly before the start of the tests and to ensure that the systems and components are restored to their normal status once the testing has been completed. For this purpose, special arrangements such as temporary interlock bypasses, temporary additional interlocks, temporary system changes and bypasses, valve configurations and instrument settings should be identified, and the step in the commissioning test procedure and/or commissioning programme for terminating these temporary arrangements should be specified. After removal of all temporary arrangement, original system configuration should be restored. Consistent with safety requirements, consideration should be given to minimum use of temporary arrangements. It should be ensured that any deviations from the normal functioning of the as-built systems do not invalidate the test objectives and jeopardise safety requirements.

5.3.6 Non-conformance to the requirement of codes and guides shall be specifically mentioned in the procedure along with the method of control and corrective action.

5.3.7 Typical contents of commissioning procedures are given in Annexure-VII.

## 5.4 Training of Manpower during Commissioning

5.4.1 Manpower requirement will be more during commissioning phase compared to that required during regular operation. Personnel engaged in commissioning activities should be suitably qualified and experienced to accept the level of responsibility and understand the importance of safety in their work. Provision should be made to train personnel who will participate in the commissioning process in specific aspects of the plant site and methods of working.

5.4.2 A training programme should be developed and implemented prior to/during commissioning to cover the following aspects:

(i) Design criteria, technical description and operational limits and conditions for the plant

(ii) Conduct of testing and maintenance in safe conditions

(iii) Methods and techniques for commissioning

(iv) Test boundaries in process, mechanical and electrical systems

(v) Work control and equipment isolation process

(vi) Environmental protection and management including waste management

(vii) Interfaces of design, construction and operation with commissioning

(viii) Interfaces of various agencies involved in commissioning

(ix) Procedural changes and design changes

(x) Permanent and temporary modifications

(xi) Reporting of non-conformances

(xii) The criteria for reporting of events

(xiii) Safety culture

(xiv) Nuclear safety, industrial safety, fire protection and radiation protection

(xv) Nuclear security.

5.4.3 Designers, manufacturers, main contractors and operators should be encouraged to participate in the training programme due to their close interaction in commissioning.

5.4.4 A safety and security culture and concern for quality should be established at all levels among the personnel involved in commissioning from the early phase. The importance of the work of those personnel performing commissioning activities for achieving quality objectives and safety objectives should be highlighted in the training programme.

5.4.5 The training programme and trainees should be subjected to periodic assessment, highlights of which should be passed on to the plant management.

5.4.6 It should be emphasised in the training programme that individuals should be aware of the significance of their duties and the possible consequences of mistakes arising from misconceptions or lack of diligence.

5.4.7 If any major events occur due to the lack of knowledge during commissioning, training should be systematically reassessed. Experience gained in commissioning should be appropriately incorporated into the training material.

5.4.8 Recommendations and guidance on the qualification and training of commissioning personnel, particularly those involved in the commissioning of safety related systems should be as per codes and guides.

5.4.9 Licensed manpower should be available prior to fuel loading in the reactor core.

**5.5 Quality Assurance during Commissioning**

5.5.1 The plant management should be responsible for establishing and implementing a quality assurance programme for commissioning. The plant management may delegate to contractors, part or all of the activities for planning, establishing and implementing the quality assurance programme for commissioning but should retain responsibility for its effectiveness.

5.5.2 Procedures should be established by the plant management to ensure that the commissioning of the plant fulfils the provisions of the commissioning programme. Arrangements should be made to ensure that these procedures are reviewed and approved before issue and that their subsequent amendment is controlled.

5.5.3 Procedures should be established for controlling the non-conformances, preventive and corrective actions taken.

5.5.4 Procedure should be established for control of documents and records.

5.5.5 All documents should be signed by the persons involved in the commissioning tests and should be vetted by the responsible engineers. The documents should also be endorsed by persons directly not involved in commissioning e.g. quality assurance personnel.

5.5.6 Periodic audit of commissioning activities should be carried out by quality assurance personnel.

**5.6 Regulatory Review during Commissioning**

5.6.1 Before authorising the hot-run, initial fuel loading, first approach to criticality and power operation, AERB will review and assess the following (as applicable):

(i) Salient design and safety features of as-built plant

(ii) Results of pre-operational commissioning tests

(iii) Operational limits and conditions (OLC)

(iv) Specific limits and conditions for operation during the commissioning of the plant from first criticality to full power

(v) Adequacy of operating procedures and instructions, especially main administrative procedures, normal operating procedures and EOPs

(vi) Staffing and management structure of the plant and arrangements for ensuring that qualification requirements are fulfilled and training is imparted

(vii) Quality assurance programme for all commissioning, operation and maintenance activities

(viii) Records and reporting system

(ix) Radiation protection programme

(x) Emergency preparedness

(xi) Arrangements for periodic testing, maintenance, inspection and surveillance

(xii) Arrangements for configuration control, especially control of plant modifications

(xiii) Measures for the safety of fissile and radioactive materials

(xiv) Adequacy of the arrangements for physical protection important to nuclear security

(xv) Adequacy of support for technical procurement, safety assurance and other matters of the plant management, as appropriate

(xvi) Complete establishment of environment survey laboratory.

5.6.2 Before licensing/authorising regular operation at full power, AERB will complete the review and assessment of the following:

(i) Results of commissioning tests and analysis reports

(ii) Final safety analysis report (FSAR)

(iii) Status of documents and pending issues.

## 5.7 Deviations, Non-conformance Control and Corrective Actions

5.7.1 During commissioning, changes in design, programme or tests may be necessary, to cope up with unusual occurrences and/or unexpected results. Deviations from written procedures, non-conformance to the requirements may also occur during commissioning. Plant management should ensure that such occurrences are minimal and procedures are established to deal with these situations. The non conformance control should be done according to the guidance stated in AERB Safety Guide titled 'Non-Conformance Control, Corrective and Preventive Actions for Nuclear Power Plants' (AERB/NPP/SG/QA-8).

*5.7.2 Proposed Changes*

(i) Methods shall be developed to ensure that proposals for changes take into account the following:

  (a) Requirements of plant management and regulatory body

  (b) Stipulations of the responsible organisation

  (c) Effects of the proposed modification on any other system

  (d) Safety implications of the proposed modification on the commissioning programme or the individual commissioning test.

(ii) The procedures for making modifications should cover design, safety reassessment, methods of implementation and testing. The scope of the assessment should correspond to the safety significance of the proposed modification.

(iii) As a result of modifications to plant systems or components, the issuing of new procedures or the revision of previously issued documents may be necessary. These changes to the procedures or documents should be authorised by means of a change notice.

(iv) An appropriate review should be performed prior to any change of sequence of commissioning tests to ensure that all the prerequisites for the out of sequence tests are met.

(v) Any changes to the approved commissioning test procedures should be controlled by means of an administrative procedure.

(vi) Unavoidable temporary modifications to the intended design configuration should be controlled. Review should be performed to ensure that the safety implications are properly addressed.

(vii) Additional guidance from applicable codes and guides should be considered for plant modifications.

5.7.3 *Unexpected Commissioning Test Results and Occurrences*

(i) Commissioning documents should contain instructions for the immediate actions to be taken if the results obtained in the course of the commissioning test fall outside the specified limits or if unexpected events occur.

(ii) A review should be carried out to find the reason for the unexpected test result and corrective actions to be taken accordingly.

## 5.8 Review of Commissioning Results

5.8.1 *Review and approval of commissioning test results*

(i) The purpose of review is to provide assurance that the performed commissioning tests demonstrate the performance of the commissioned systems is in accordance with the design intent. Operational constraints (if any) of the systems have been identified. It should ensure that all necessary data have been collected and analysed, technical evaluation has been completed and commissioning report has been prepared. The review should also provide assurance that the succeeding phase/sub-phases can be conducted safely and the safety of the plant does not depend on the performance of untested structures, systems or components. The evaluation of the commissioning results should include a comparison with the acceptance criteria.

(ii) Personnel assigned to carry out reviews should have had adequate experience in their field of specialisations.

5.8.2 *Documenting the commissioning results*

Documents should be prepared and issued in accordance with the established procedures during the progress of the commissioning activities. The following type of documents are used:

(i) Test Certificate

A test certificate is drawn up to certify that the commissioning test has been completed in accordance with the authorised procedures or, if otherwise, it should state any reservations about, departures from, or limitations to the procedures.

(ii) Phase/sub-phase completion certificate

A phase/sub-phase completion certificate is produced at the time of review to certify that all the commissioning tests in the phase/sub-phase have been satisfactorily completed (listing any reservations). It should also list the associated commissioning test certificates.

(iii) Approval Certificate

An approval certificate is issued by the plant management to permit the commissioning programme to continue after review of one phase/ sub-phase to another. Where required, the plant management should obtain approvals from AERB.

*5.8.3 Phase/Sub-phase completion Review*

(i) At the end of a phase/sub-phase, the results of the commissioning in that phase/sub-phase and the general condition of the plant should be reviewed by the representatives of the commissioning group and the plant management, prior to seeking approval to begin the next phase/sub-phase, in accordance with the requirements of AERB.

All commissioning reports for the phase/sub-phase should be prepared and all commissioning completion certificates should be issued before the review.

(ii) Review should ensure that all systems and special testing equipment for the commissioning tests in the next phase/sub-phase will be available before proceeding to that phase/sub-phase and all relevant administrative and control procedures will be complied with, as documented.

(iii) A close liaison should be maintained with all participants in the commissioning programme, including personnel of the plant management and personnel of AERB so that phase/sub-phase completion and approval documents can be produced expeditiously. Provision should exist for continuous update of the documents.

*5.8.4 Reporting*

(i) Summary reports should be prepared for quick assessment of the commissioning results. Formal comprehensive commissioning reports containing all the required information, including collation and final evaluation of the test results, should be prepared. These commissioning reports should be retained for record.

(ii) Formal reports for each phase and sub-phases should be prepared by the individuals responsible and should be approved by the commissioning group. The format of a report may vary. A typical format is given in Annexure-VIII of this guide. (also see section 4.4.1).

## 5.9 Contingency Planning

5.9.1 The plant management should ensure that an appropriate organizational plan is in place for managing emergencies during commissioning. Radiation emergency handling arrangements should be in place and should be tested before the commencement of fuel loading.

5.9.2 Emergency handling arrangements should also cater to hazards such as fire, flood, etc.

5.9.3 A potential nuclear hazard could arise if an operating unit is adjacent to the unit under commissioning. Emergency handling arrangements should be made for the protection of construction and commissioning personnel. Emergency handling arrangements should take into account any other local hazard(s).

5.9.4 Those involved in the commissioning should be trained to cope with any anticipated emergency.

5.9.5 Radiation emergency procedures should be prepared as per codes and guides.

# 6. INTERFACES AMONG CONSTRUCTION, COMMISSIONING AND OPERATIONAL ACTIVITIES

## 6.1 General

6.1.1 Construction, operation and maintenance related activities may need to be performed in parallel with the commissioning of the plant. The interfaces between these activities should be adequately managed to ensure the safety of the plant and personnel and to ensure that the commissioning programme is not impaired.

6.1.2 Work control procedures should be established to coordinate the activities of all groups involved in commissioning and to cover the major work activities, including post-work testing. These procedures should provide for the proper channelling of the work to the person responsible for the system and for ensuring notification and awareness in the control room of all the work activities that are in progress.

## 6.2 Interfaces between Construction and Commissioning Activities

6.2.1 Organisational setup should include clear and well understood lines of authorisation and communication between construction and commissioning activities.

6.2.2 The construction organisation may have responsibility for some activities during the commissioning programme. This responsibility should be defined well in advance of the commencement of this programme in order to prevent misunderstanding. The activities of the construction organisation during the commissioning programme should be properly scheduled so as to meet the requirements for construction and commissioning.

6.2.3 The interface between construction and commissioning should be considered in following areas:

(i) Procedures and sequence for transferring structures, systems and components for commissioning consistent with commissioning priorities

(ii) Prerequisites to start the commissioning programme

(iii) Special precautions necessary for the commissioning of partly installed systems (the responsibility of the commissioning group for repeat testing of the systems those have been commissioned initially as partially installed)

(iv) Methods of identifying technical, operational and other staffing requirements

(v) Continuous review of the construction progress with regard to any possible impact on commissioning

(vi) Return of systems for rectification of defects identified during commissioning tests

(vii) Testing of equipment following rectification of defects by the construction group

(viii) Written permission for first energizing of systems to establish control under the safety work permit rules

(ix) Preservation of structures, systems and components before, during and after commissioning as appropriate.

## 6.3 Interfaces between Commissioning and Operational Activities

6.3.1 The following particular aspects should be considered in relation to the interface between commissioning and operating activities:

(i) Procedures for transferring structures, systems and components for operation including methods of identifying the special technical, operational or staffing restrictions necessary as a result of partial completion of construction or commissioning activity

(ii) Baseline data derived from commissioning, such as the issuing of formal commissioning reports and a statement of the existing radiological and industrial safety conditions

(iii) Changes in responsibility for safety reviews; implementation of modifications to the plant and to operating techniques; and nomination of competent persons

(iv) Modifications to the plant and procedures

(v) Availability of as-built drawings, instructions and procedures for operating and maintaining the systems and the plant

(vi) Conditions for access of personnel taking into account the segregation requirement between systems already in operation and systems being commissioned, including security requirements

(vii) Control of temporary procedures and equipment; for example, special start up instrumentation or duplicate safety keys and authorisation for the use of jumpers and lifted leads

(viii) The implementation of operating and maintenance requirements for structures, systems and components as each system is transferred to the operation group

(ix) Provision of sufficient opportunity for the operating personnel to become both trained in and familiar with the operating and maintenance techniques for the plant

(x) Provisions for verification and validation of procedures for operation and surveillances and EOP (to the extent possible)

(xi) Procedures for radiation monitoring and protection of site personnel and for keeping records of occupational exposures during the commissioning

(xii) Training in radiological safety and authorisation of commissioning personnel to work in the controlled areas

(xiii) Reassessment of routine operating and maintenance instructions and procedures in the light of experience gained during commissioning

(xiv) Development of arrangements and instructions for emergency preparedness

(xv) Keeping records of information that could have implications for decommissioning and subsequent handover of these records to the operation group (e.g. records of cyclic loading, other unusual occurrences that could have long term effects)

(xvi) Adherence to normal operating practices such as access to the control room, control of information, access to control cabinets and switchboards, communications with the control room about abnormalities and changes in plant configuration especially after the core has been loaded with nuclear fuel

(xvii) Establishment of adequate personal access control procedures and security arrangements.

# APPENDIX-A

## FUEL LOADING

A. 1 **For safely accomplishing initial fuel loading into the reactor and ensuring that inadvertent criticality does not occur during the loading process, account should be taken of the items listed in this Appendix.**

A. 2 **Prerequisites of Fuel Loading**

The following activities and checks must be completed before fuel loading:

(i) Required cleanliness of reactor pressure vessel (RPV) and reactor coolant system is ensured. PSI of RPV and its internal components, piping, reactor coolant pump volute casing, steam generator, pressuriser and all welded joints is performed. Verification of the configuration of all relevant systems as specified in the design documentation

(ii) Iinspections of fuel assemblies, reactivity control devices and other absorbers, and identification of the fuel (careful distinction should be made between different types of fuel and different grades of enrichment, and note taken of which of the elements are 'poison' elements)

(iii) Operability of nuclear start up instrumentation, in terms of proper calibration, location (source–fuel–detector geometry) and functionality, including audible and visual alarm indications in the control room. The response of the instrumentation to a neutron source should be proven

(iv) Status of the containment and the primary circuit, with components correctly placed or removed, as specified

(v) Status of the coolant such as fluid quality and level, as specified in the loading procedures, with systems and components arranged and secured to prevent changes to their status. Examples are valves, pumps and other equipment lock-outs

(vi) Operability of appropriate reactivity controls and readiness for reactor shutdown by maintaining negative reactivity by poison addition

(vii) Conformity of the reactivity condition of the reactor core with specifications, and ensuring of the shutdown margin by making conservative assumptions about conditions and by locking off power supplies to prevent the inadvertent 'removal' (reduction) of negative reactivity

(viii) Availability of approved procedure for handling, storing and monitoring of neutron sources (if used) for reactor startup

(ix) Operability of fuel handling equipment, including on-site trials of fuel handling equipment using dummy fuel assemblies and verification and validation of fuel handling software and relevant EOPs

(x) Status of protection systems, interlocks, mode switches, alarms and radiation protection equipment as prescribed; high flux trip points set for a relatively low power level (approximately 1% of full power). Availability of measures to ensure sub criticality

(xi) Composition of the fuel handling crew and availability of experienced Reactor Physicist, and their duties and responsibilities in the event of emergencies

(xii) Operability of radiation monitors, nuclear instrumentation, and manual and automatic devices for actuating building evacuation alarms and ventilation controls, establishment of Health Physics Unit, establishment of access control, provision of water level measurement inside RPV; availability of emergency power supply for lighting

(xiii) Availability of approved 'Technical Specifications for Operation'

(xiv) Authorisation for fuel loading by AERB.

**A. 3 Important Considerations for Fuel Loading Procedure**

The following items should be included in the procedures for the fuel loading:

(i) Fuel handling, including the precautions to be taken to prevent criticality and physical damage

(ii) Loading sequences and patterns for the different types of fuel (in terms of grades of enrichment and poisoning), control rods, and other absorbers and components

(iii) Guidance on fuel addition to the core along with fuel loading sequence so that the reactivity worth of the individual fuel elements inserted decreases as the core is assembled

(iv) Details of the information that should be maintained on the fuel inventory and control rod inventory in the core and in storage, and details of appropriate records of core loading

(v) Information on proper seating and orientation of fuel assembly, its components, checking of fuel identification and availability of action plan to correct deviation observed, if any

(vi) Requirements for nuclear instrumentation and neutron sources for monitoring sub-critical multiplication, including methods for relocation of sources or detectors and normalisation of count rate after relocation (a minimum number of source range monitors should be required to be operable whenever operations are performed that could affect the reactivity of the core)

(vii) Neutron flux monitoring information, including counting times and frequencies, as necessary, for plotting a curve for inverse multiplication and interpreting plots using readings from at least two channels

(viii) Expected sub-critical multiplication behaviour

(ix) Determination of the boron concentration at a frequency commensurate with the worst case dilution capability, with account taken of the piping systems attached to the reactor coolant system

(x) Actions to be taken during periods when fuel loading is interrupted, especially those pertaining to flux monitoring

(xi) A method of maintaining adequate communication between the control room and the loading station

(xii) The minimum number of qualified personnel necessary to load fuel

(xiii) Establishment of criteria for cessation of fuel loading, such as unexpected sub-critical multiplication behaviour, loss of communication between the control room and the fuel loading machine, inoperability of a source range monitor or inoperability of the shutdown system

(xiv) Specified limits of the counting period for count rates

(xv) Establishment of criteria for reducing the fuel loading increment, if applicable (if this increment is reduced because of excessive sub-critical multiplication, it must not be increased again)

(xvi) Establishment of criteria for emergency injection of fuel poison

(xvii) Specified limits for the quality (chemistry parameters and boron concentration) of the reactor coolant, water temperature and radioactivity in reactor coolant system and associated systems

(xviii) Establishment of criteria for containment evacuation

(xix) Actions to be taken in the event of fuel damage

(xx) Actions to be taken or approvals to be obtained before resuming fuel loading, in cases, where any stated limits have been reached or exceeded

(xxi) Emergency procedures to take care of the situation in case of inadvertent criticality

(xxii) Monitoring of radiological conditions after fuel loading.

# ANNEXURE-I

## DOCUMENTS TO BE VERIFIED DURING COMMISSIONING OF NUCLEAR POWER PLANT (TYPICAL)

### I.1 General

Commissioning activities offer excellent opportunities to validate and improve operational documents. Hence operational documents should be ready before the corresponding commissioning activity.

The following documents, required for subsequent operation, should be prepared and verified during commissioning of nuclear power plant:

### I.2 Routine Operational Documents

(i) Operating manuals

(ii) Operational flow sheets

(iii) Electrical diagrams

(iv) Process and instrument diagrams

(v) As built drawings

(vi) Maintenance manuals, equipment history cards and other maintenance documents

(vii) In-service inspection procedures and forms

(viii) Surveillance test procedures (e.g. containment testing, protective system testing, tests or safety systems

(ix) Various forms (OFS forms) such as class IV power failure record sheet, routine panel reading data sheets for control room and local panels (if any), jumper sheets etc.

### I.3 Documents to be Prepared by Design Group for Plant Operation

(i) Technical specification for operation

(ii) Final safety analysis report

(iii) It is desirable to have a preliminary design PSA level-I report.

### I.4 Documents to be prepared for Safety, Emergency and Security of the Plant

(i) Emergency operating procedures

(ii) Accident management procedures

(iii) Emergency preparedness procedures (plant, site, offsite, personal emergency and security)

(iv) Radiation protection procedures

(v) Radiation emergency procedures

(vi) Station protection code

(vii) Disaster management plan

(viii) Procedures for nuclear security.

**I.5 Other Documents**

(i) Special checklists such as checklist for criticality, crossing $90^0$C etc.

(ii) Routine procedures like shift handing over etc.

(iii) Configuration control procedures including procedure for ECNs, updating drawings and other documents, writing technical bulletins after ECNs are completed etc.

# ANNEXURE-II

## BASELINE DATA TO BE COLLECTED FOR MAINTENANCE AND LIFE CYCLE MANAGEMENT (TYPICAL)

II.1 Baseline data is required for life management, maintenance, timely replacement etc. to ensure that required safety levels are maintained. Several nuclear power plants had to be taken out of service just because safe residual life could not be demonstrated due to lack of baseline data and establishing impact of various life degradation factors. Life management must start from infancy i.e. from design/manufacturing stage (even from raw material procurement stage). While PSI forms an important part of baseline data, there are other important data such as conditions of support and structure of safety related equipment, equipment capability parameters, condition monitoring data etc, which need to be collected.

II.2 Thus collection of baseline data for SSC should be started from the stage of manufacturing, tests conducted at manufacturer's shop, tests carried out during construction/erection, tests carried out during commissioning and initial operation. Utility should identify important parameters to be monitored in the above mentioned stages for life cycle management maintenance, timely replacement etc. and incorporate these parameters in appropriate test procedures. For many equipment ASME power test codes list the parameters and the methodology of how they have to be measured. These data should be recorded and preserved permanently. Following are the typical baseline data to be collected:

(i) Valves and dampers: opening and closing times, valve stroke length, position indication, torque and travel limiting settings, calibration of control valves, operability of check valves at differential pressures, settings and functioning of safety relief valves, water hammer, liner adjustment, number of cycles of operation with individual air cylinders including air check valve performance, fail safe operation, live loading for gaskets. For control valves and control loops including controllers, proportional band, gain, A/B, response time etc need to be collected.

(ii) Motors and generators: checks on support structure, direction of rotation, vibration signature, overload and short circuit protection, margins between set points and full load running current, winding and bearing temperatures, phase to phase voltage, current and insulation resistance checks, neutral current, acceleration under load, temperature rise under specified cold and hot starting conditions, phase currents and load acceptance capability versus both time and load (for generators), terminal tightness values, contact resistance etc.

(iii) Pumps, Fans and Gas blowers: checks on support structure, vibration signature data, motor load versus current, flow and pressure characteristics, alignment, bearing temperature, acceleration and coast down time, 100% capability test results.

(iv) Piping : Thickness check and inspection of welded (VT, UT, RT and DPT) or mechanical joints, hydro test data, thickness measurement at bends, Helium leak test, pipe support installation and adjustment, amount of expansion/contraction during heating up/cooling down.

(v) Vessels including reactor pressure vessel: Inspection of vessel thickness and welded joints, hydro test data, calibration of vessel for inventory, clearance of obstructions; support adjustments; support bolt installation and tensioning; insulation; rupture disc, relief valve/ vacuum breaker set value, ductility and fracture toughness, creep and radiation induce embrittlement, (coupons to be designed and installed).

(vi) Heat exchangers including steam generators: Visual Inspection, inspection of welded joints, measurement of heat exchanger tube thickness, number of unacceptable tubes, bolt torque values and gasket compression, terminal temperature difference, flow values of different fluids at new condition and position of inlet and outlet valves, tube to tube sheet joint effectiveness, 100% capability test results.

(vii) Diesel Generator Sets: Fuel consumption at no load and full load, number of starts possible by compressed air receivers/battery, temperature and pressure of cooling water and lubricant, flow requirement of cooling water, terminal temperature of heat exchangers, calibration of diesel storage tanks, vibration during no load and full load, cylinder exhaust temperature, 100% capability test results.

(viii) Transformers: Insulation resistance values between phases, between phases and neutral, break down value of oil, temperature, primary and secondary winding impedances, various parametrical data on no load and full load, tap changer settings etc; 100% capability test results.

(ix) Switchgears: Closing and tripping time, insulation resistance values between phases, between phases and neutral, setting of relays, di-electric constant value of insulating material, contact resistances.

(x) Cables: Insulation resistances among cores for multi core cables and earth, contact resistance of joints.

(xi) Relays: Time, current, temperature etc. for different type of relays, pick up voltage and drop out voltage values.

(xii) Batteries: Float and boost charging currents, physical composition of electrolyte, capacity testing, terminal voltage difference, 100% capability test results.

(xiii) Instrumentation and control : voltage, frequency, current, trip settings, operation of prohibiting and permissive interlocks, calibration of equipment, response and delay time, drifting of settings of parameters, physical values of flow elements, master clock settings.

(xiv) Containment Structure: Integrated Leakage Rate Test for initial leakage rate establishment, Pre-stressing values in stressing cables, stress and strain readings taken from the embedded instrumentation in containment, values of stress and strain during peak pressure in containment during proof test, tilt and absolute settlement values.

(xv) Other Civil Structures: Visual inspection of identified places for periodic surveillance, seismic anchorage inspection etc.

(xvi) Safety System Performances: Performance parameters like flow, temperature and pressure measurements for baseline data generation for system performance evaluation and periodic surveillance. Equipment performance data collection as per items listed in items (i ) to (xii). These systems include engineered safety features and corresponding supporting systems.

(xvii) Normal Operating System Performances: Performance parameters like flow, temperature and pressure measurements for baseline data generation for system performance evaluation and operational data collection during normal and abnormal operations. Equipment performance data collection as per items listed in items (i ) to (xii). These systems include all systems of nuclear power plant and corresponding supporting systems ventilation balancing data, pressure gradients etc need also to be collected.

(xviii) Environmental Survey: Collection of environmental data over a period of time to generate a dependable database for environmental parameters.

(xix) Chemical parameters.

(xx) Some special equipment like shut off rods , pressuriser etc. will have special data such as drop times, reactivity worth, pressuriser performance capability etc.

**II.3 Pre Service Inspection and In Service Inspection to be carried out for Life Cycle Management**

In service inspection (ISI) involves periodic examination of components of NPP during its lifetime. The examinations required to determine the health of components form a part of ISI programme. The results of the pre service inspection (PSI) of the components prior to the start of operation of the plant establish the baseline data required for comparison during subsequent ISI. PSI should therefore be carried out to collect baseline data before start up of the plant, to ensure that the components are of acceptable quality as per applicable standards/codes prior to the start of plant operation.

**II.4 Pre Service Inspection to be carried out to generate baseline data for subsequent In Service Inspection**

In establishing the extent of the in-service inspection programme, consideration should be given to the following systems and components in accordance with their importance to safety:

(i) Pressure retaining parts of components in the reactor coolant system

(ii) Components of or connected to the primary reactor coolant system that are essential for ensuring the shutdown of the reactor and cooling of the nuclear fuel in relevant operational states and in postulated accident conditions

(iii) Other components, such as main steam lines or feed water lines, whose dislodgement or failure might put in jeopardy the systems mentioned in items (i) and (ii) above.

**II.5 Areas to be examined shall include:**

II.5.1 Piping

(i) At least 10% of the total area to be examined for ISI of the system.

(ii) All the areas for which recordable level (>20% of amplitude for reference standard) indications were detected earlier.

II.5.2 Vessels

(i) The full length of all major nozzle welds shall be inspected.

(ii) The most significant indications detected previously in the longitudinal and circumferential joints, such that at least 10 PSI/ ISI areas (or all, if fewer than 10 exist) per component or 10% of the indications (starting from the most severe indication in descending order), whichever is greater, shall be examined.

II.5.3 Pumps

(i) At least 10% of all the pumps in each category for a reactor unit shall be examined.

(ii) The examination shall include all category A and B (see subsection 4.1.6.2 of 'In Service Inspection of Nuclear Power Plants' (AERB/NPP/SG/O-2) pressure-containing welded joints and internal surfaces of pump components designated as category A and B examination areas.

II.5.4 Valves

(i) At least 10% of all the valves for a reactor unit shall be inspected.

(ii) The valve inspection shall include all category A and B pressure-containment weld joints and internal surfaces of valve components designated as category A and B inspection areas.

II.5.5 Supports

At least 10% of all the supports of equipment, vessels, pipe, etc. (including snubbers) shall be examined.

II.5.6 Steam Generator Tubes

(i) At least 10% of the tubes selected for ISI in each steam generator, including the tubes with the most significant indications detected previously, shall be examined.

(ii) Tubes to be inspected should be selected in accordance with the requirements mentioned in 13.1.2 of 'In Service Inspection of Nuclear Power Plants' (AERB/NPP/SG/O-2).

II.5.7 Heat Exchanger Tubes

Inspection of 100% of the tubes is recommended in view of observed frequent failures of heat exchanger tubes.

**II.6 The PSI and ISI shall be carried out in accordance with documented and approved procedures.**

The examination methods and techniques used shall comply with the requirements of the ASME Boiler and Pressure Vessel Code on ISI (section-XI) and Non Destructive Examination (section-V).

**II.7 Equipment history cards that are used by maintenance groups are to be initiated during commissioning.**

# ANNEXURE-III

## LIST OF HAZARDS AND MALFUNCTIONS DURING COMMISSIONING (TYPICAL)

**III.1 Hazards**

(i) Over pressure leading to rupture disc burst, opening of safety or relief valve discharging high pressure fluid into work place/ surroundings

(ii) Steam/high enthalpy water leak

(iii) Improper insulation of pipelines and components containing high temperature fluid

(iv) Hazards due to fire occurring in the areas having fire loads

(v) Hazards due to storage and during handling of chemicals

(vi) Electrical hazards: due to improper earthing, weak insulations, short circuits, cable over heating causing fire, condensation in sealed terminal box leading to blast and fire, water ingress into electrical equipment (motor, junction box, terminal box etc), improper cable joints leading to heat generation and fire etc.

(vii) Oil spillage leading to personal injury and fire

(viii) Hazards due to ionizing radiation including storage and handling of radioactive materials and sources

(ix) Hazards due to leakage of fluid from the system such as chlorine, $CO_2$ , Nitrogen (within confined atmosphere)

(x) Other industrial hazards not included in above list

(xi) Hazards of external origin (cyclone, tsunami, flood, earthquake, lightning etc).

**III.2 Malfunctions**

III.2.1 Malfunctions of Mechanical Components

(i) Failure of relief valves/safety valves and rupture discs

(ii) Over speed of rotating equipment

(iii) Failure of process equipment such as pumps, blowers, fans, heat exchangers, valves dampers etc. during commissioning tests

(iv) Detachment of component of a rotating equipment generating internal missile within the equipment damaging the equipment internally or external missile which can damage the surrounding equipment or personnel

(v) Failure of cylinders containing high pressure fluids

(vi) Failure of supports of SSC

(vii) Failure of couplings for rotating equipment.

III.2.2 Malfunctions of Electrical Components

(i) Power failure during commissioning tests which requires continuous electrical power

(ii) Breaker failure ( fail to trip/close when required)

(iii) Failure of contactors, mechanical relays, switches

(iv) Failure of UPS, batteries and associated chargers

(v) Failure of electrical protections (current, voltage and frequency).

III.2.3 Malfunctions of Instrumentation and Control Equipment

(i) Failure of gauges, switches controllers for maintaining pressure, temperature and level leading to high pressure, high temperature and over flows

(ii) Failure of window annunciation

(iii) Failure of interlocks

(iv) Communication failure

(v) Impulse line failure

(vi) Control power failure

(vii) Failure of software.

III.2.4 Malfunction of Process

(i) Cooling water failure

(ii) Cooling air failure

(iii) Lubrication system failure

(iv) Compressed air failure

(v) Ventilation system failure

(vi) Spurious start of stand by equipment (pumps, heaters, fans etc. parallel to operating equipment) leading to high pressure/vacuum and temperature of the system.

III.2.5 Hazards due to Improper Sequence of Commissioning

(i) Commissioning of components/systems before commissioning of the protective devices such as: rupture discs, relief devices etc.

(ii) Annunciation of malfunction/trouble not available/not commissioned for a commissioned system

(iii) Failure of electrical equipment (e.g. motors, transformers etc) due to improper setting of protective relays at supplier's shop

(iv) Commissioning of system without commissioning it's support systems like cooling water system, electrical system, compressed air system etc.

# ANNEXURE-IV

## PRE OPERATIONAL CHECKS

**IV. 1 Introduction**

This Annexure provides a detailed listing of checks to be considered in the development of a commissioning programme.

**IV. 2 Functional Checks of Individual Sub Systems or Components**

The following are the typical checks on different type of equipment to be considered[3] :

(i) Valves and dampers: operation of actuators, leakage, opening and closing times, valve stroke, position indication, torque and travel limiting settings, operability at differential pressures, correct settings and functioning of relief and safety valves.

(ii) Motors and generators: direction of rotation, vibration, overload and short circuit protection, margins between set points and full load running current, winding and bearing temperatures, lubrication, insulation tests, supply voltage, phase to phase checks, neutral current, acceleration under load, temperature rise under specified cold and hot starting conditions, phase currents, and load acceptance capability versus both time and load (for generators).

(iii) Pumps, fans or gas blowers: vibration, motor load versus time, seal or gland leakage, seal cooling, flow and pressure characteristics, alignment, lubrication, bearing temperature, acceleration and coast down, protection against reverse rotation.

(iv) Piping and vessels: pressure tests, leak tightness, cleaning and flushing, clearance of obstructions, support adjustments, proper gasket installation, bolt tensioning, insulation, filling and venting, inventory calibration of tanks and vessels.

(v) Instrumentation and control: voltage, frequency, current, circuit breaker operation, bus bar transfers, trip settings, operation of prohibiting and permissive interlocks, calibration and response time.

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3 Some items are applicable only to important or special components and some tests may be included in the pre-operational phase/sub-phase itself. Some special equipment (like reactor coolant pumps) needs special tests over and above the standard tests. These tests should be included in the commissioning procedures and carried out at appropriate stage of commissioning.

## IV. 3 Reactor Coolant System

IV. 3.1 The reactor coolant system includes all pressurized components such as pressure vessels including pressuriser, piping, pump and valve bodies forming the pressure boundary of the primary coolant for the reactor, together with such items as the associated pumps, valves and instrumentation.

IV.3.2 System checks: expansion and restraint checks to confirm acceptability of clearances and displacements of vessels, piping, piping hangers, hold down support or restraining devices such as those for seismic protection in the as-built system; hot run and/or cold run of the system with simultaneous operation of auxiliary systems, including aspects of chemical parameter control.

IV.3.3 Component checks: appropriate checks and measurements of reactor coolant system components, including:

(i) Pressuriser

(ii) Pumps and associated motors

(iii) Steam generators

(iv) Pressure relief valves (and associated tanks and cooling circuits, if any) and the supports and restraints for discharge piping

(v) Safety valves

(vi) Special types of valves

(vii) Other valves

(viii) Instrumentation used for monitoring system performance and chemical parameters or performing prohibiting and permissive interlock functions

(ix) Reactor vessel and internals including installation of surveillance coupons of reactor pressure vessel material

(x) Ejectors.

IV.3.4 Vibration checks: vibration monitoring of reactor internals and other components such as piping systems, heat exchangers, steam generator tubing and rotating machinery.

IV.3.5 Pressure boundary integrity tests: baseline data for subsequent in-service testing, leakage, valve passing etc.

## IV. 4 Reactivity Control Systems

Checks on the reactivity control systems include the following:

(i) Checks of the chemical and volume control system: proper blending of boric acid solution and reactor coolant, uniform mixing, adequacy of sampling and analytical techniques, operation of heaters and trace heating; operation of instrumentation, controls, interlocks and alarms; rate of injection into and dilution from the bulk system; redundancy, electrical independence and operability of system components; correctness of failure mode on loss of power to system components.

(ii) Checks of the liquid poison system for normal shutdown, ATWS and LOCA: operation of the system with de-mineralized water; mixing with reactor coolant and adequacy of the sampling system; operability of instrumentation, controls, interlocks and alarms; operability of trace heating; operation of pumps and quick acting valves; redundancy and electrical independence.

(iii) Checks of the control system and shut-off system: normal operation and shutdown capability including cooling requirements; scram times and, where applicable, drop time tests; appropriate performance of inhibition and other functions in the system logic (such as group selection, rod selection, insertion, withdrawal and runback features, sequence control devices); instrumentation for rod position and interaction of the control and shut-off drive systems with other systems such as automatic reactor power control systems and re-fuelling equipment; correct failure mode on loss of power for the rod drive systems; appropriate operation of system alarms.

**IV. 5 Reactor Protection Systems**

Checks on the reactor protection systems include: response time of protection channels, including sensors and associated hardware between the measured variable and the input to the sensor (such as snubbers); operation in all combinations of logics, calibration and operability of primary sensors, trip and alarm settings, operation of prohibiting, permissive and bypass functions, and operability of bypass switches; operability in conjunction with other systems, redundancy, coincidence, electrical independence and safe failure on loss of power; operability of the devices provided to protect the plant from anticipated operational occurrences in conjunction with failure to trip automatically. Any defensive measure to ensure the integrity of the protection system also has to be tested (such as key interlock systems or electromagnetic devices).

**IV. 6 Fuel Storage and Handling**

Tests on fuel storage and handling systems are required to demonstrate the operability of the equipment and components used for storing and handling of non-irradiated fuel, handling and cooling of irradiated fuel in accordance with the design intent. These tests may include:

(i) Tests of fuel handling equipment at storage facility for non-irradiated fuel

(ii) Integrity testing or inspection of spent fuel storage, its liner and gates

(iii) Tests on cooling and purification systems for spent fuel facilities (including the testing of anti-siphon devices, high radiation alarms and low water level alarms)

(iv) Tests on re-fuelling equipment (including hand tools, power equipment, bridge and overhead cranes, and grapples) and operability of protective interlocks and devices

(v) Tests on containment devices and leakage and ventilation in the fuel discharge route

(vi) Tests on fuelling machines, control and hydraulic systems

(vii) Appropriate tests or inspections of storage facilities for ensuring sub-criticality

(viii) Handling tests on fuel transfer flasks

(ix) Defective fuel assembly detection system.

**IV. 7 Containment Systems**

In tests on the primary and secondary containment systems, account should be taken of the functional requirements during normal operation such as those for heating, ventilation and air conditioning, as well as isolation and integrity requirements under simulated accident conditions. Particular attention should be paid to:

(i) Structural integrity test (proof test) of containment structure

(ii) Integrated leakage rate test of containment structure including local leakage rate test of penetrations, air locks, valves and dampers

(iii) Functional tests of isolation valves on initiation of logic including closing time

(iv) Containment vacuum breaker test

(v) Functional test of the ‘containment auxiliary system’ such as purge system, system for air purification, gas treatment system etc.

(vi) Primary and secondary ventilation system tests; leak collection and exhaust system tests, and pressure suppression system (e.g. dousing or spray water system tests).

In addition, leakage rate test of stack may also be considered.

### IV. 8 Handling Systems for Reactor Components

Tests on the handling systems for reactor components cover equipment handling, hoists used for reactor components that need to be moved (e.g. for refuelling or for reactor vessel inspection), and protective interlocks on cranes and hoists.

### IV. 9 Engineered Safety Features

IV.9.1 Engineered safety features prevent or mitigate the consequences of postulated accidents. Since they vary for different plant designs, the following list is illustrative only of those features commonly provided:

(i) Emergency core cooling systems and essential auxiliary systems for equipment operability using normal and emergency power and cooling supplies, design pump run out conditions and injection at required flow rate and pressure; operability of overpressure protection for low pressure cooling systems

(ii) Emergency gas removal system

(iii) Systems for post-accident removal of heat from the containment structure, containment spray system and recirculation fans

(iv) Control system for combustible gases in the containment

(v) Over pressure protection of primary circuit and secondary circuit

(vi) Emergency cooling water supply system for components

(vii) Emergency cooling system for steam generators

(viii) Quick boron supply system for handling ATWS condition

(ix) Passive heat removal system (PHRS) for removal of decay heat from reactor core during Station Black Out (SBO) condition

(x) Core catcher and associated systems for retaining and cooling molten corium.

IV.9.2 Tests on the engineered safety features include tests for satisfactory performance and response time in all expected operating configurations or modes, operation of initiating devices, correct logic and set points, operation of bypasses, prohibiting and permissive interlocks and protective devices for equipment that could shut down or defeat the operation or functioning of engineered safety features. Concurrent testing of systems or components, provided to ensure or support the operation of engineered safety features, should also be conducted using the minimum number of operable components available with which these systems are designed to function. These include systems for heating, ventilation and air conditioning, cooling water and seal injection systems and protected compressed gas supplies. Protective devices, such as leak tight covers or housings provided to protect engineered safety features from flooding, or devices used to prevent the ‘water hammer’ effect and possible damage to fluid systems, are also included.

**IV. 10 Systems for Disposal of Radioactive Waste**

Tests on radioactive waste disposal systems include those designed to demonstrate the integrity, operability and verify the performance of systems and components used to process, store and release, or to control the release of liquid, gaseous and solid radioactive waste, and of pumps, tanks, controls, valves and other equipment, including automatic isolation and protective features, instrumentation and alarms; and systems designed to verify tank volumes, capacities, hold up times, and proper operation and calibration of associated instrumentation.

**IV.11 Radiation Protection**

Appropriate tests on systems and components used to monitor or measure radiation levels to provide for personnel protection or to control or limit the release of radioactive material include the following:

(i) Process tests, effluent tests and area radiation monitor tests

(ii) Tests on personnel monitors, effluent monitors and radiation survey instruments

(iii) Tests on laboratory equipment used to analyse or measure radiation levels and activity concentrations

(iv) In situ efficiency tests of high efficiency particulate air filters and adsorption filters.

**IV.12 Instrumentation & Control System**

IV.12.1 Tests on instrumentation and control systems cover control functions for normal operation and instrumentation to provide alarms for off-normal conditions in order to initiate corrective action and to monitor events. Instrumentation and control systems should be tested over the design operating range, and limiting malfunctions and failures should be tested by simulation. Any defensive measure to ensure the integrity of the instrumentation and control system also has to be tested (such as electromagnetic interference).

IV.12.2 A list of instrumentation parameters and equipment used for testing (some of this equipment may be tested in conjunction with the control system) should typically include the following:

(i) Pressuriser pressure and level

(ii) Reactor vessel water level in normal operating condition as well as during accidental condition

(iii) Reactor coolant flow

(iv) Feed water control

(v) Automatic control of reactor power and temperature

(vi) Steam pressure in the secondary system

(vii) Detectors of reactor coolant system leaks

(viii) Reactor and primary circuit diagnostic systems

(ix) Instrumentation initiating the emergency core cooling system, containment isolation and containment spray

(x) Annunciators for reactor control and engineered safety features

(xi) Equipment to measure chemical parameters

(xii) Reactor start up instrumentation

(xiii) Instrumentation and controls used for shutdown from outside the control room

(xiv) In-core and out-core neutron instrumentation

(xv) Detection of failed fuel

(xvi) Traversing in-core probes

(xvii) Monitoring of loose parts

(xviii) Pressure control to maintain design differential pressures

(xix) Seismic instrumentation

(xx) Detectors monitoring the external and internal flooding conditions

(xxi) Instrumentation monitoring the course of postulated accident conditions

(xxii) Post-accident hydrogen monitors and analysers used in the control system for combustible gas

(xxiii) Computer control, monitoring and logging systems

(xxiv) Control system for emergency transfer of electrical loads.

IV.12.3 Independent verification and validation of software used in computer based system should be carried out by an independent committee. The report of this committee will be audited by AERB.

**IV.13 Electrical Systems**

Appropriate tests are to be carried out on the plant electrical systems including the normal AC power distribution system, the emergency AC power supply and distribution system, and the DC power supply and distribution system.

IV.13.1 Normal AC power distribution system: operation of protection devices, initiating devices, relay and logic devices, breakers, motor controllers, switchgear, transformers, transfer and trip devices, prohibiting and permissive interlocks, instrumentation and alarms, load shedding capabilities, redundancy and electrical independence, integrated system performance with simulated partial and full loss of off-site power under worst case conditions, and capability to transfer from on-site to off-site power sources.

IV.13.2 Vital bus bar and associated AC power supplies: load tests that use either all the sources of power supplies to bus bars or the minimum number.

IV.13.3 DC system: calibration and trip settings of protective devices, including relaying devices, operation of breakers, prohibiting and permissive interlocks; capability of battery chargers, transfer devices, inverters, instrumentation and alarms used to monitor system availability including under voltage alarms and ground detection instrumentation; redundancy, electrical independence and actual total system loads, discharge test of each battery bank at full load and for the design duration of load, adequacy of emergency lighting.

IV.13.4 Emergency AC power distribution system: operation of protection devices, relay and logic devices, breakers, motor controllers, switchgear, transformers, transfer and trip devices, prohibiting and permissive interlocks, instrumentation and alarms, load shedding capabilities, capability of emergency and vital loads to start in the proper sequence and to operate under simulated accident conditions with both the normal (preferred) AC power sources and/or the emergency (standby) power sources in accordance with design requirements for voltage and frequency; duration tests of diesel generators or equivalent machines, capability to start and operate with maximum and minimum design voltage available; testing of emergency or vital loads conducted for a sufficient period of time to provide assurance that equilibrium conditions are attained (to the extent practicable); verification of system redundancy and electrical independence; testing of loads supplied from the system such as motor generator sets with flywheels, power and control

UPS designed to provide uninterrupted power to vital plant loads, to demonstrate proper operation; load tests for vital bus bars using normal and emergency sources of power supplies to the bus bar; operation of indicating and alarm devices used to monitor the availability of the emergency power system in the control room; adequacy of the plant's emergency lighting system.

IV.13.5 Emergency or standby AC power supplies: redundancy, electrical independence, and proper voltage and frequency regulation under transient and steady state conditions; performance of auxiliary systems such as those used for starting, cooling, heating, ventilating, lubricating and fuelling, with the duration of the test being sufficient to ensure that equilibrium conditions are attained; logic, correct set points for trip devices and proper operation of initiating devices, prohibiting and permissive interlocks, redundancy and electrical independence.

## IV.14 Power Conversion System

The power conversion system includes all the components provided to transfer the reactor's thermal energy in normal operation from the boundaries of the reactor coolant system to the main condenser, and those systems and components provided for the return of condensate and feed water from the main condenser to complete the cycle. System expansion, restraint and operability checks and other appropriate checks are to be carried out on the following systems and components:

(i) Steam generators

(ii) Steam and feed water process lines

(iii) Auxiliary feed with systems

(iv) Relief and safety valves for steam generator pressure

(v) Emergency feed water pump

(vi) Stop, control, intercept and bypass valves for the turbine

(vii) Turbine generator and associated systems

(viii) Feed water system

(ix) Condensate system

(x) Condenser circulating water system

(xi) Makeup water and chemical treatment systems

(xii) Steam extraction system

(xiii) Control system for the hot well level of the main condenser, lerd of deacrator and steam generator

(xiv) Feed water heaters and drainage systems

(xv) Main condenser auxiliaries used for maintaining condenser vacuum

(xvi) Condenser off-gas system.

**IV.15 Auxiliary and Miscellaneous Systems**

Appropriate tests are to be conducted to demonstrate the operability of auxiliary and miscellaneous systems and, where appropriate, to verify redundancy and electrical independence. The following list is illustrative of the types of systems whose performance is demonstrated by testing:

(i) Reactor coolant makeup system: capability during all operational states and accident conditions

(ii) Seal fluid system

(iii) System for seal and pump cooling fluid

(iv) Vent and drainage systems

(v) Fire protection systems, including manual and automatic operation of fire detection, alarm and suppression systems

(vi) Service water and raw water systems

(vii) Heating, cooling and ventilation systems, including control room habitability systems, detection systems for smoke and toxic chemicals, ventilation shutdown devices, and systems for leak tightness of ducts and flow rates, direction of airflows and control of space temperatures

(viii) Compressed gas systems, including the instrument air system and other compressed gas systems used for safety related functions

(ix) Residual heat removal system

(x) Cooling system for reactor core isolation

(xi) Shield cooling system

(xii) Leak detection system: sensitivity and accuracy to detect leakage of primary fluid through the boundaries of the reactor coolant system

(xiii) Boron recovery system

(xiv) Communication systems: emergency siren, public address system within the plant, systems that may be used if the plant is required to be shut down from outside the control room, and communication systems required by the facility emergency plan

(xv) Chemistry control systems for the reactor coolant system and secondary coolant systems

(xvi) Cooling and heating systems associated with spent fuel storage, if necessary

(xvii) Equipment and controls for establishing and maintaining sub-atmospheric pressure in sub-atmospheric containments

(xviii) Component cooling water systems

(xix) Reactor coolant and secondary sampling systems

(xx) Closed loop cooling water systems

(xxi) Purification and cleanup systems

(xxii) Diesel storage and distribution system

(xxiii) Acid, Alkali and other reagents system

(xxiv) Effluent treatment system

(xxv) Chlorination system.

# ANNEXURE-V

## FUEL LOADING, INITIAL CRITICALITY AND LOW POWER TESTS

### V. 1 Tests during Fuel Loading and Initial Criticality Period

Before reactivity is increased (‘inserted’) to approach initial criticality, the prerequisites for fuel loading, open vessel tests and final checks are to be completed to ensure that the reactor is in proper condition for start up. The following list is illustrative of the types of tests and verifications that are conducted during or after initial fuel loading:

(i) Tests for withdrawal and insertion speeds of reactivity control rods, sequences, rod position indication, protective interlocks and circuitry, and scram timing of reactivity control and shut-off devices after the core is fully loaded; to the extent practicable, testing should demonstrate scram times for reactivity control rods at the extreme temperatures and flow ranges for the reactor coolant system.

(ii) Local criticality tests, if applicable.

(iii) Testing of the reactor protection system: trip point, logic and operability of auto scram and manual scram functions.

(iv) Rod drop time measurements: each rod, cold and hot, at rated recirculation flow and with no recirculation flow, additional measurements for each of the fastest and slowest rods.

(v) Tests to assess leakage rate from the reactor coolant system.

(vi) Chemical tests: water quality and boron concentration of the reactor coolant (concentration of $B^{10}$ isotope).

(vii) Calibration and neutron response check of source range monitors, calibration of intermediate range neutron flux measuring instrumentation, and verification of proper operation of associated alarms and protective functions. In-situ response check of neutron monitors and instrumentation at early stage of reactivity addition.

(viii) Monitoring with mechanical and electrical in-core equipment, including traversing in-core probes, if installed.

(ix) Flow tests for the reactor coolant system: verification of vibration levels, verification of differential pressures across the fully loaded core and differential pressures across major components in the reactor coolant system; verification of the reactions of the piping to transient conditions (such as pumps starting and stopping) and to flows for all allowable combinations of pumps in operation; loss of flow tests conducted to measure flow coast down.

(x) Functional checks on all parameters and controls provided in the backup control room.

(xi) Test of the effectiveness of the pressuriser (hot shutdown).

(xii) Vibration checks or monitoring.

(xiii) Shutdown margin verification for partially and fully loaded core.

**V. 2 Low Power Tests**

After achieving initial criticality, tests are performed as necessary to verify that the behaviour and characteristics of the core, cooling system, reactivity control systems, reactor physics parameters and shielding are as expected, and that the reactivity coefficients are as assumed in the safety analysis report. Tests are also performed to confirm the operability of plant systems and design features that could not be completely tested during the pre-operational test phase owing to the lack of an adequate heat source for the reactor coolant system and the main steam system. The following list is illustrative of the tests to be conducted, as applicable, if they were not completed previously during pre-operational hot functional testing.

(i) Neutron and gamma radiation surveys.

(ii) Determination of adequate overlap of source range and intermediate range neutron instrumentation, and verification of alarms and protective functions intended for operation in the low power test range; checks on changes in detector sensitivity as a result of changes in temperatures of coolant and shielding.

(iii) Radiation monitors: verification of their proper response to a known source.

(iv) Measurement of the temperature reactivity coefficient for poison and/or coolant over the temperature range and poison concentration range in which the reactor may become critical.

(v) Determination of reactivity worth for control rods and the control rod bank, including verification of the rod insertion limits required to ensure an adequate shutdown margin, consistent with the assumptions made in accident analysis (e.g. with the control rod of maximum reactivity worth failing to enter the core).

(vi) Determination of the reactivity worth of the most reactive rod.

(vii) Operability of the control rod withdrawal and insertion sequencers and of the inhibit or block functions associated with control rod withdrawal up to the reactor power level at which such features must be operable.

(viii) Measurements of absorber reactivity worth (boric acid concentration and burnable absorber rods etc).

(ix) Determination of the absorber concentration at the initial criticality.

(x) Flux distribution measurement with normal rod patterns (this may be performed at a higher power, consistent with the sensitivity of in-core flux instrumentation).

(xi) Chemical and radiochemical measurements to demonstrate the design capability of the chemical control systems and of the installed analysis and alarm systems to maintain water quality within limits in the reactor coolant and secondary coolant system.

(xii) Chemical tests of control fluid quality.

(xiii) Comparison of the actual critical configuration with the predicted configuration.

(xiv) Confirmation of the calibrations of reactivity control devices as predicted for standard rod patterns (for non-standard patterns, the differential and integral reactivity worth are to be determined).

(xv) Capability of the primary containment ventilation system to maintain the design parameters in the containment and to maintain important components in the containment within design limits, with the reactor coolant system at its rated temperature and with the minimum availability of ventilation system components for which the system is designed to operate.

(xvi) Demonstration of the operability of steam driven engineered safety features and steam driven plant auxiliary equipment and power conversion equipment.

(xvii) Verification of piping and component movements, vibrations and expansions for the acceptability of safety systems; operability, including stroke times, of isolation valves and bypass valves for the main steam line and branch steam line at rated temperature and pressure conditions; operability of the leakage control system for the main steam isolation valve.

(xviii) Operability of the computer system for process control.

(xix) Test of scram time for control rods and shutdown rods at rated temperature in the reactor coolant system.

(xx) Operability of pressuriser relief valves and main steam system relief valves at rated temperature.

(xxi) Operability of residual heat removal systems or decay heat removal systems, including atmosphere steam discharge valves and condenser steam dump valves.

(xxii) Operability of purification and cleanup systems for the reactor coolant system.

(xxiii) Vibration measurements or checks of reactor vessel internals and of components of reactor coolant systems.

(xxiv) Functional test of cooling system for reactor vessel head.

# ANNEXURE-VI

## POWER TESTS

The following list is illustrative of the types of performance demonstrations, measurements and tests in the power tests phase/sub-phase.

(i) Tests of power reactivity coefficients.

(ii) Tests of dynamic plant response to the design load swings, including step and ramp changes, and to verify that the response of automatic control is in accordance with design (at 25%, 50%, 75% and 100% full power).

(iii) Evaluation of core performance: reactor power measurements, verification of the calibration of flux and temperature instrumentation, with sufficient measurements and evaluations conducted to establish flux distributions, local surface heat flux, linear heat rate, departure from nucleate boiling ratio, radial and axial power peaking factors, maximum average planar linear rate of generation of heat, minimum critical power ratio and quadrant power tilt throughout the permissible range of power and flow conditions.

(iv) Test of dropped rod: effectiveness of instrumentation in detecting a dropped rod and verification of associated automatic actions.

(v) Evaluation of flux asymmetry with a single rod assembly both fully and partially inserted below the control bank, and evaluation of its effects.

(vi) Determination of the reactivity worth of the most effective rod.

(vii) Verification of SCRAM times after plant transients that result in SCRAM.

(viii) Measurement of power control during flow variation and demonstration of flow control.

(ix) Operation of control rod sequencers, rod withdrawal block functions, rod runback, partial SCRAM and 'select rod insert' features.

(x) Operation of reactivity control systems, including functioning of control and shutdown rods and poison addition systems.

(xi) Test of the capability of plant systems to control oscillations in xenon levels in the core.

(xii) Natural circulation tests of the reactor coolant system.

(xiii) Chemical analyses.

(xiv) Functioning of chemical and radiochemical control systems and sampling to verify that the characteristics of the reactor coolant system and secondary coolant system are within specified limits.

(xv) Vibration monitoring of reactor internals in steady state and transient operation, if this testing has not been completed previously.

(xvi) Evaluation of performance of shutdown cooling system; capability test of all systems and components provided to remove residual heat or decay heat from the reactor coolant system (including condenser steam dump valves or atmosphere steam discharge valves, residual heat removal system in steam condensing mode and shutdown cooling system) and testing of the auxiliary feed water system to include provisions that will provide reasonable assurance that excessive flow instabilities (such as 'water hammer') will not occur during subsequent normal system start up and operation (before exceeding 25% power).

(xvii) Performance of reactor core shutdown cooling system (after shutdown from over 25% power).

(xviii) Determination of the dynamic response of the plant and the subsequent steady state of the plant for single and credible multiple trips of the reactor coolant pump.

(xix) Demonstration of effectiveness of leak detection systems for reactor coolant, if not previously demonstrated.

(xx) Operation of failed fuel detection systems in accordance with predictions.

(xxi) Performance of the auxiliary systems whose operable components have the minimum design capability for operation of the engineered safety features.

(xxii) Test of shutdown and all other operations which can be performed from backup control room.

(xxiii) Process computer: comparison of safety related predicted values with measured values; verification of inputs to control room computers or process computers from process variables, data printouts and validation of performance calculations performed by the computer; validation of all computer safety functions.

(xxiv) Calibration of reactivity control devices, as necessary, and verification of the performance of major or principal plant control systems such as the average temperature controller, automatic reactor control systems, integrated control system, pressuriser control system, reactor coolant flow control system, main, auxiliary and emergency feed water control systems, hot well level control systems, steam pressure control systems and reactor coolant makeup and blow-down control systems.

(xxv) Shielding and penetration cooling systems: maintenance of temperatures of cooled components with the minimum design capability of cooling available.

(xxvi) Performance of ventilation systems and air conditioning systems.

(xxvii) Functional tests of relief valves; verification of operability, response times, set points and reset pressures, as appropriate, for pressuriser relief valves, main steam line relief valves and atmosphere steam discharge valves.

(xxviii) Turbine trip tests.

(xxix) Tests of generator main breaker trip: with the method used for opening the generator output breakers (by simulating an automatic trip) selected such that the turbine generators will be subjected to the maximum credible over speed condition they could encounter during plant operation.

(xxx) Tests with loss of off-site power (>10% of generator power output).

(xxxi) Verification of operability and response times of isolation valves for the main steam line and the branch steam line.

(xxxii) Calibration and tests of the pressure regulator, including response to operation of a bypass valve.

(xxxiii) Performance of emergency condenser (after shutdown from over 25% power) if applicable.

(xxxiv) Trip of feed water pump and restart of standby pump.

(xxxv) Test of the dynamic response of the plant for a simulated condition of loss of turbine generator coincident with loss of off-site power.

(xxxvi) Test of the dynamic response of the plant to load rejections including turbine trip (this test may be combined with the turbine trip test if a turbine trip is initiated directly by all remote manual openings or automatic trips of the generator main breaker; i.e. a direct electrical signal, not a secondary effect such as turbine over speed).

(xxxvii) Test of the dynamic response of the plant for the case of automatic closure of all main steam line isolation valves (the test may be made at a lower power level to demonstrate proper plant response to this transient).

(xxxviii) Test of the dynamic response of the core and plant to fast load changes initiated by the load control.

(xxxix) Test of the dynamic response of the plant to loss of or bypassing of the feed water heater(s) due to a credible single failure or operator error that result in the most severe case of a reduction in feed water temperature.

(xl) Neutron and gamma radiation surveys to determine the effect of shielding.

(xli) Radiation monitors: verification of their proper response to a known source.

(xlii) Effluent monitoring systems: verification of calibration by laboratory analysis of samples (as early in power ascension as possible and repeated at defined power steps).

(xliii) Process radiation monitoring systems and effluent radiation monitoring systems and auto actions/isolations if utilized: correctness of response.

(xliv) Operation of processing, storage and release systems for gaseous and liquid radioactive waste.

(xlv) Continuous operation of plant for a specified period of time (typically 100 full power days), at full power, as agreed between regulatory body and the utility before obtaining licence for regular operation.

## ANNEXURE-VII

### CONTENTS OF COMMISSIONING PROCEDURES (TYPICAL)

The contents of the commissioning procedure should include following sections.

(i) Introduction: A summary of the main commissioning objectives and the safety aspects to be demonstrated in relation to the phases/sub-phases of the main commissioning programme.

(ii) Objectives and Methods: Objectives of the commissioning tests and the methods by which they will be achieved should be stated

(iii) Limiting criteria: Applicable operational limits and conditions

(iv) Prerequisites and Initial conditions: The state of all relevant systems which are likely to affect or be affected by the system under commissioning should be given together with conditions and precautions, if any, needed to maintain the desired system configuration

(v) Commissioning Methodology: The way in which the system to be commissioned should be brought out with details of the commissioning by a step by step format. Procedures may contain sketches to the extent required depicting the systems to be commissioned indicating all equipment mentioned in the procedure

(vi) List of Instrumentation and Special Test Equipment: Any special test equipment and calibrations required should be specified

(vii) Acceptance Criteria: Acceptance criteria should be given. The acceptance criteria of all the commissioning tests should be as per approved design and related safety documents

(viii) Manpower Requirements, Qualification and Responsibilities: Manpower requirement, qualifications and assignment of duties and responsibilities for conducting commissioning

(ix) Special Precautions: Special precautions for the safety of personnel and equipment

(x) Commissioning Tests Completion: Certification on satisfactory completion of commissioning tests and systems brought to normal operating conditions

(xi) Data Collection, Processing and Evaluation: Collection of baseline data including information that is to be kept on permanent records as per the approved tabulated format. Commissioning tests data sheets should be standardized and each sheet should be signed by the person collecting the data. Chronological recording is desirable (commissioning data, date and time). Techniques of analysing data and the results of measurements should be stated, including the manner of obtaining verifications, and the extent of the check calculations made should be reported in the results

(xii) Non-conformance with the Requirements of Codes and Guides: Non-conformance shall be specifically mentioned in the procedure along with the method of control and corrective action

(xiv) Identification, Referencing and Distribution: Unique identification of procedure, cross reference and distribution list.

# ANNEXURE-VIII

## FORMAT FOR COMMISSIONING REPORTS (TYPICAL)

After commissioning of structures, systems and components, commissioning reports should be prepared. The commissioning report should contain the following but not limited to:

(i) Introduction

(ii) References to appropriate commissioning procedures

(iii) Summary of commissioning objectives

(iv) Conduct of the commissioning tests including the initial and final states of the plant, the actual limitations experienced, and the problems encountered and the actions taken to overcome them, including any modifications to the plant or to the procedures.

(v) Concise description of any special test equipment used

(vi) Summary of data collected and analyses of the data

(vii) Evaluations of results, including statements that the acceptance criteria have been met

(viii) Conclusion

(ix) Identification, cross-references and a distribution list.

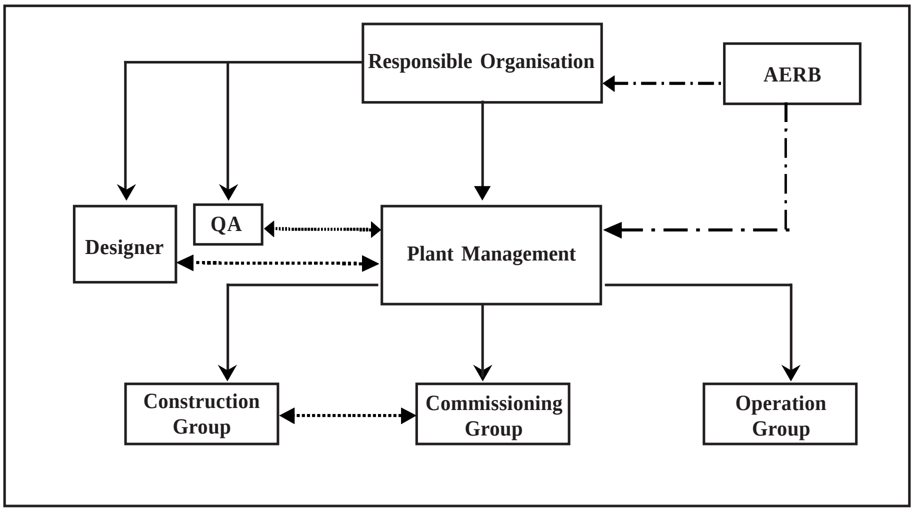


**FIG. 1 : TYPICAL ORGANISATION CHART DURING COMMISSIONING OF NUCLEAR POWER PLANTS**

**LEGEND**

Line of authority for construction, commissioning and operation

Line of communication

Line of regulation

## FIG. 2 : TYPICAL COMMISSIONING ACTIVITY DIAGRAM FOR PWR BASED NPP

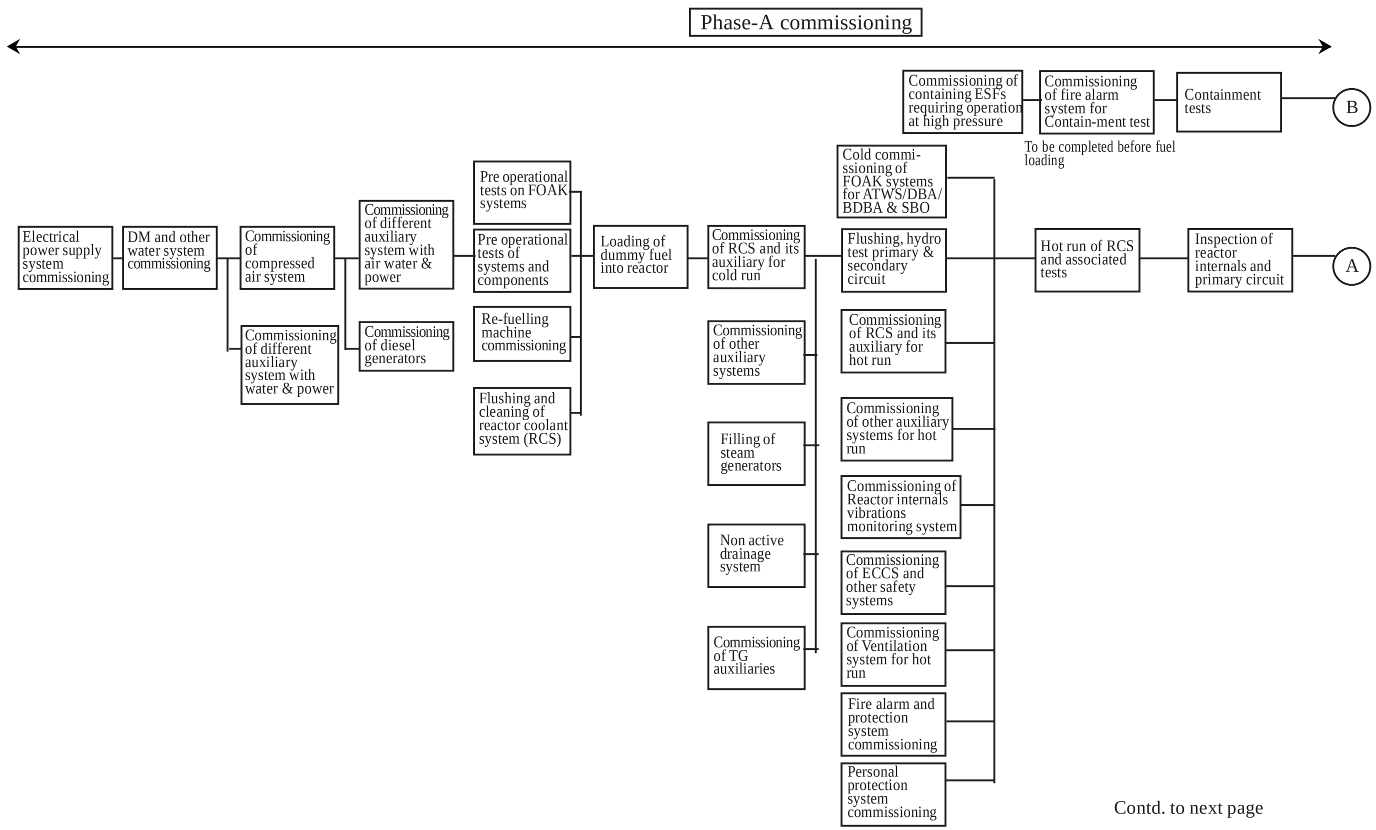


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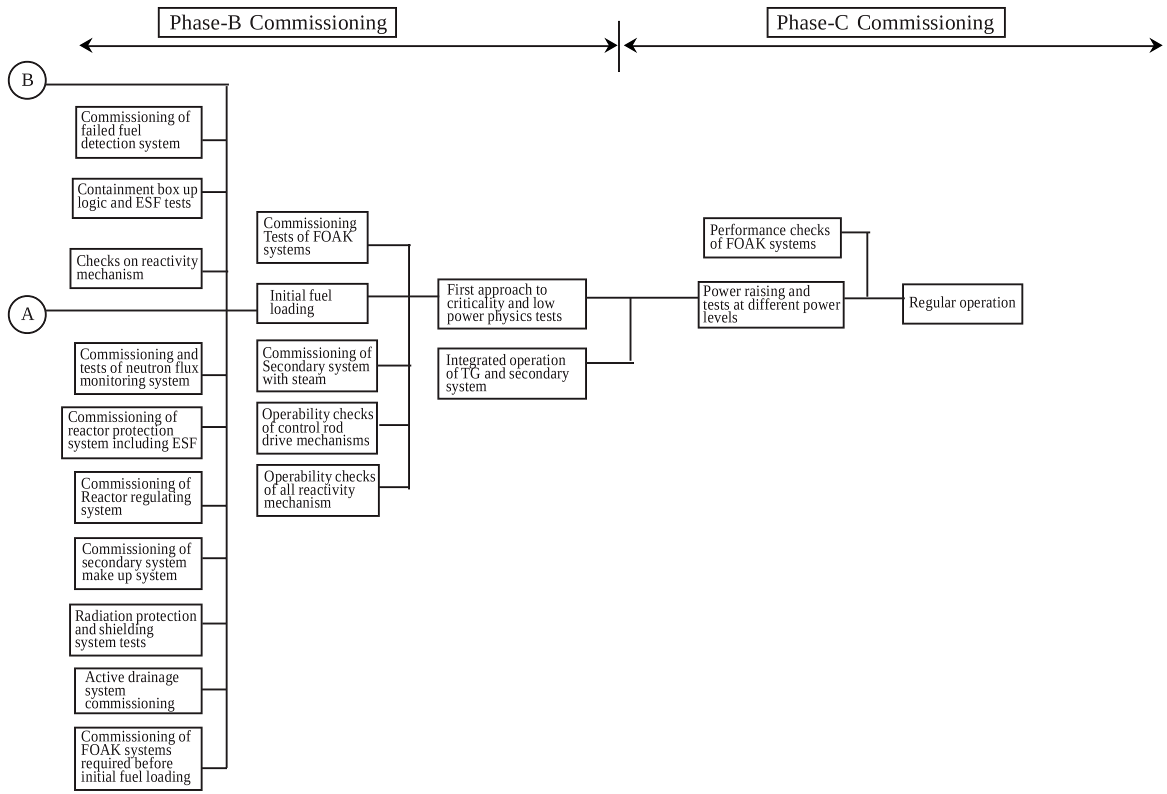
**FIG. 2 : TYPICAL COMMISSIONING ACTIVITY DIAGRAM FOR PWR BASED NPP (Contd.)**



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## PROVISIONAL LIST OF SAFETY CODE, GUIDES, MANUAL AND TECHNICAL DOCUMENTS OF SAFETY IN NUCLEAR POWER PLANT OPERATION

| Safety Series No. | Title |
|---|---|
| AERB/SC/O | Code of Practice on Safety in Nuclear Power Plant Operation |
| AERB/SC/O (Rev. 1) | Nuclear Power Plant Operation |
| AERB/SG/O-1 | Staffing, Recruitment, Training, Qualification and Certification of Operating Personnel of Nuclear Power Plants |
| AERB/SG/O-2 | In-Service-Inspection of Nuclear Power Plants |
| AERB/SG/O-3 | Operational Limits and Conditions for Nuclear Power Plants |
| AERB/SG/O-4 | Commissioning Procedures for Pressurised Heavy Water Reactor Based Nuclear Power Plants |
| AERB/NPP/SG/O-4C | Commissioning of Pressurised Water Reactor Based Nuclear Power Plants |
| AERB/SG/O-5 | Radiation Protection During Operation of Nuclear Power Plants |
| AERB/SG/O-6 | Preparedness of Operating Organisation for Handling Emergencies at Nuclear Power Plants |
| AERB/SG/O-7 | Maintenance of Nuclear Power Plants |
| AERB/SG/O-8 | Surveillance of Items Important to Safety in Nuclear Power Plants |
| 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-11 | Management of Radioactive Waste Arising During Operation of Pressurised Heavy Water Reactor based Nuclear Power Plants |

## PROVISIONAL LIST OF SAFETY CODE, GUIDES, MANUAL AND TECHNICAL DOCUMENTS OF SAFETY IN NUCLEAR POWER PLANT OPERATION (CONTD.)

| Safety Series No. | Title |
|---|---|
| AERB/SG/O-12 | Renewal of Authorisation for Operation of Nuclear Power Plants |
| AERB/SG/O-13 | Operational Safety Experience Feedback on Nuclear Power Plants |
| AERB/NPP/SG/O-14 | Life Management of Nuclear Power Plants |
| AERB/NPP/SG/O-15 | Proof and Leakage Rate Testing of Reactor Containments |
| AERB/NF/SM/O-1 | Probabilistic Safety Assessment for Nuclear Power Plants and Research Reactors |
| AERB/NF/SM/O-2 | Radiation Protection for Nuclear Facilities (Rev. 4) |
| AERB/NPP/TD/O-1 | Compendium of Standard Generic Reliability Database for Probabilistic Safety Assessment of Nuclear Power Plants |
| AERB/NPP/TD/O-2 | Human Reliability Analysis: A Compendium of Methods, Data and Event Studies for Nuclear Power Plants |

**AERB SAFETY GUIDE NO. AERB/NPP-PWR/SG/O-4 C**

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