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## Commissioning for Nuclear Power Plants

### DRAFT SPECIFIC SAFETY GUIDE SSG

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## 1. INTRODUCTION

### BACKGROUND

1.1. This Safety Guide supplements the IAEA Specific Safety Requirements publication on Safety of Nuclear Power Plants: Commissioning and Operation [1] and provides recommendations on meeting the requirements established in Section 6 on plant commissioning. The present Safety Guide supersedes the IAEA Safety Guide on Commissioning for Nuclear Power Plants that was issued as Safety Standards Series No. NS-G-2.9 in 2003.

1.2. The revision of the Safety Standards Series publication No. NS-G-2.9 was conducted in accordance with the following:

- The technical content of the previous Safety Guide was kept largely unchanged but was updated where necessary;
- Additional recommendations resulting from the development of other IAEA safety standards and other publications and from recent experience in the area of commissioning were included;
- The text has been restructured to be in accordance with the logic of organizing, managing and conducting commissioning for a nuclear power plant;
- The content gives more explicit attention to the roles of the regulatory body and the operating organization.

### OBJECTIVE

1.3. The objective of this Safety Guide is to make recommendations on the basis of international good practices in commissioning for nuclear power plants, as currently followed in Member States. This will enable the commissioning for a nuclear power plant to proceed safely and to a high quality. It will also enable the necessary assurances to be provided that the plant has been constructed in accordance with the design intent and can be operated safely.

1.4. Some or all of this Safety Guide may be relevant when a nuclear power plant is to be restarted after an extended shutdown period. Where extensive modifications have been made to an existing nuclear power plant, the commissioning of these modifications and their incorporation into the plant may require comprehensive tests to demonstrate that the plant meets the original or the modified design requirements. The commissioning of modifications to a nuclear power plant is covered in Ref. [2]; however, all or part of this Safety Guide may be used.

### SCOPE

1.5. This Safety Guide deals with the commissioning of land based stationary thermal nuclear power plants of all types. It makes recommendations on how to meet the requirements on the commissioning programme; organization and management; testing and review procedures; and the interfaces between organizations involved in the commissioning

activities, including the regulatory body. It also deals with the control of changes in the commissioning programme and with the documentation required for and produced in commissioning.

1.6. This Safety Guide is focused on activities performed at the plant site. However, off-site activities also have to be considered in specifying the commissioning programme and in deciding whether systems, structures and components are operational.

1.7. This Safety Guide does not cover considerations of nuclear security in commissioning for a nuclear power plant. Guidance on nuclear security is issued in the IAEA Nuclear Security Series.

## STRUCTURE

1.8. Section 2 relates to the entire commissioning process for a nuclear power plant. The objectives of commissioning are covered as well as recommendations for the preparation and approval of the commissioning programme. The different stages of commissioning are covered in accordance with the practices commonly adopted by States. The roles of the regulatory body and of the operating organization during commissioning in relation to approval, authorization and supervision are also covered.

1.9. Section 3 describes organizational matters in the commissioning process, including the functions and responsibilities of the parties involved and the interfaces between them. It covers the characteristics of the management system that are of particular relevance to commissioning, and includes management for safety, quality management and qualification of the personnel involved in commissioning. The organizational interfaces between construction, commissioning and operation are covered, as well as the management of handover of the plant.

1.10. Section 4 covers practical issues relating to the implementation of the commissioning programme. The commissioning stages and different aspects of the testing that forms the core of the commissioning programme are presented and discussed. Initial loading of nuclear fuel as well as the achievement of initial criticality is dealt with. Regulatory authorization during commissioning and authorization for subsequent stages are dealt with.

1.11. Section 5 deals with the documentation to be prepared and produced during commissioning, and the requirements for the records over the lifetime of the plant.

1.12. The Appendix specifies prerequisites for the loading of nuclear fuel and presents specific items to be included in the procedures for fuel loading. The Annex lists examples of typical commissioning tests.

## 2. THE COMMISSIONING PROCESS

2.1. Commissioning is an essential process for the subsequent safe operation of a nuclear power plant and should be carefully developed, planned, executed and regulated. The commissioning process should be considered a progressive transition between construction and operation of the plant.

2.2. Good coordination and communications should be established among all participants in the commissioning process (designers, construction group, licence holder, regulators, manufacturers, commissioning groups and operating groups). All the parties involved should be informed of all pertinent decisions.

#### OBJECTIVES OF COMMISSIONING

2.3. Commissioning has the objective of demonstrating that the nuclear power plant as constructed meets the design requirements and the safety requirements as specified in the safety analysis report and in the license conditions. For the achievement of this objective and to ensure safe and reliable operation of the plant in the future, the commissioning process should include activities for the following purposes:

- To verify that structures, systems and components fulfill the design safety objectives through the corresponding acceptance criteria;
- To collect base line data for equipment and systems for future reference;
- To validate those operating procedures and surveillance procedures for which the commissioning tests provide representative activities and conditions; and to validate by trial use, to the extent practicable, that the facility's operating procedures, surveillance procedures and emergency procedures are adequate;
- To familiarize the operating, maintenance and technical staff of the nuclear power plant with the operation of the plant.

#### THE COMMISSIONING PROGRAMME

2.4. The commissioning programme should cover all the activities to be performed on structures, systems and components to make them operable in accordance with the design intent. It should also cover, to the extent possible, the plant conditions considered in the safety analysis report and in the license conditions. It should allow for verifying — while the plant remains in a safe domain — the assumptions made in the safety analysis report and the existence of adequate margins between the design intent and safety requirements and the actual performance of the plant.

2.5. In the commissioning programme to be performed on-site, account should be taken, to the fullest extent possible, of tests performed off the site. Tests that are taken into account should be adequately justified for their on-site application to structures, systems and components as installed and as integrated with their physical and functional interfaces in the nuclear power plant.

2.6. The commissioning programme should include the consideration of chemical preconditioning and/or passivation of the plant prior to active commissioning. Conditioning of the plant will minimize the future production of corrosion products, activated products and contaminated materials, which will reduce radiation doses to personnel in future operations.

2.7. As part of the commissioning programme a detailed list of commissioning activities should be prepared. Responsibilities for implementing and reporting on the various parts of the commissioning programme should be clearly specified. In planning for commissioning, all activities and all organizations involved should be taken into consideration.

2.8. In planning for commissioning, adequate provision should be made for the allocation of responsibilities for safety at different milestones of the commissioning programme, especially with reference to:

- The delivery of nuclear fuel onto the site, and the safe storage of nuclear fuel, including control of access to buildings and the operation and monitoring of relevant systems;
- The first fuel loading, and as applicable, together with moderator/reflector enacting the linking of safety with operation of the nuclear power plant.

2.9. The commissioning programme should be structured and appropriately justified so as to ensure the following:

- All the tests necessary to demonstrate that the plant meets the design intent as stated in the safety analysis report are performed (the annex provides a typical list of tests to be taken into account in developing the commissioning programme);
- The tests are performed in a logical sequence: in particular, tests are arranged to be progressive, so that the plant is exposed to less onerous conditions before it is exposed to more onerous conditions;
- The tests are grouped in commissioning stages in a logical sequence from non-nuclear testing stages to nuclear testing stages, and from testing stages for individual systems and components to overall testing stages for integrated systems, with overall testing stages for the plant at the end;
- The appropriate hold points are established for the commissioning process;
- Operations personnel, maintenance personnel and support personnel are further trained and processes and procedures are validated;
- Milestones are identified, including milestones at which the regulatory body's authorization is required to proceed in the process of commissioning;

2.10. Whatever are the organizational arrangements for commissioning of the nuclear power plant; the operating organization should review and approve the commissioning programme.

2.11. The commissioning programme should include:

- Any applicable requirements of the regulatory body, including the witnessing of specified tests;
- The designation of each test together with a unique identification;
- Cross-references to other documents relevant to commissioning;
- Provision for the means for data collection for future use.

2.12. During commissioning, normal operating procedures, including those for operational periodic tests should be widely used to validate the applicability of the procedures. The emergency operating procedures should also be validated in the commissioning programme, to the extent possible.

2.13. The commissioning programme should include provisions to ensure that operating personnel and maintenance personnel in all disciplines participate to the extent possible in commissioning activities and that the operating procedures are validated with the participation of plant staff to the extent practicable. Designers and other specialists should be involved in the development and review process for commissioning and test programmes, procedures and results.



2.14. The commissioning programme should provide a framework for the scheduling of tests and related activities, and for suitable personnel and equipment to be available at the proper time. The programme should also provide for the timely production of all documentation.

2.15. The commissioning programme should be written in such a form as to enable the objectives and methods of testing to be readily understood by all concerned and to allow control and coordination by management.

2.16. The commissioning programme should be prepared in the framework of the existing management system of the operating organization, with proper consideration given to all aspects of management.

## STAGES OF COMMISSIONING

2.17. The commissioning programme for a nuclear power plant should be divided into stages whose number and size will depend upon safety requirements, technical, administrative and regulatory requirements when applicable. A review of the results of the stage tests should be completed before continuing to the next stage. The review should enable a judgment to be made on whether the commissioning programme may continue to the next stage, and whether the succeeding stages should be modified as a consequence of the test results or because some tests in the stage were not undertaken or were not satisfactorily completed. The impact on safety of the incompleteness or the omission of tests should be given due consideration before proceeding with further testing.

2.18. In addition, if the sequence of tests in a stage of commissioning is significant for safety, sub-stages may be required by the operating organization or the regulatory body. Each stage and sub-stage should be followed by a review before the next stage is started. Before the start of initial criticality tests, low power tests and power ascension tests, all the tests at the previous stages should be satisfactorily completed. Open issues, if any, should be accepted as being required to be cleared prior to or at the next stage.

2.19. On the basis of the broad range of commissioning practices in States, the commissioning process can be divided into the following stages and sub-stages in order to obtain the responses of all important systems for different values of operating parameters:

- Non-nuclear testing, which includes:
  - individual pre-operational tests of systems and components;
  - overall pre-operational systems tests;
  - structural integrity tests, integrated leakage rate tests of the containment structure and primary system and secondary system;
- Nuclear testing, which includes:
  - initial fuel loading;
  - subcritical tests;
  - initial criticality tests;
  - low power tests;
  - power ascension tests;

2.20. The sequence of tests in each sub-stage should be given in the order in which the tests are expected to be performed. Adjustment in the test sequence can be performed according to progress of the tests, the test results or external conditions such as the availability of

supporting systems and supporting facilities (for example: the availability of the electrical grid, of water treatment, etc.), the need for periodic tests or the performance of maintenance activities. These adjustments should take due consideration of safety aspects, and should be controlled to ensure the same level of review as the original sequence. The adjustments should result from a common agreement of the commissioning organization and the operation organization and of the regulatory body where necessary.

2.21. Each stage and/or sub-stage of commissioning should include the tasks necessary for the preparation of the succeeding stage and/or sub-stage, and in particular the availability requirements of the systems for the succeeding stage.

2.22. The relevant safety system settings and alarm settings, including those of instruments for radiological protection, should be specified at the appropriate commissioning stages or sub-stages.

## EXECUTION OF THE COMMISSIONING PROGRAMME

2.23. Testing, as the core of the commissioning programme, should be sufficiently comprehensive to demonstrate that the plant can be operated in all modes for which it has been designed to be operated. However, under any of the following conditions, tests should not be conducted and operating modes or plant configurations should not be established:

- If they have not been analysed and found to be safe;
- If they fall outside the range of assumptions made in the safety analysis report;
- Or if they might damage the plant or jeopardize its safety.

A risk assessment should be carried out before the commencement of each test and any necessary precautions should be taken in accordance with its findings.

2.24. Appropriate and extensive tests of the safety functions for the nuclear power plant and for safety related structures, systems and components should be identified and executed.

2.25. In determining the sequence of testing, the following points should be carefully considered:

- Systems that are so identified should undergo prior testing so that they are available for the proper testing of other systems;
- Systems that are so identified should be operational to ensure that other systems can be tested without risks to workers and without jeopardizing the safety of the plant;
- Relevant tests should be grouped together in a stage (or sub-stage) of testing of systems;
- simultaneous tests may have an influence on each other's results;

2.26. During nuclear power plant construction, a period of inactivity and the construction of other equipment may alter the test results of equipment which have already been commissioned. This should be considered for the planning of the commissioning tests, especially for standby components which are not operated regularly.

2.27. Specific programmes and procedures should be written in support of the commissioning programme. These programmes and procedures should describe the principles, objectives and nature of the tests. They should include the criteria for judging the validity of the results and

the acceptance criteria. These procedures for systems important to safety should contain checks that all performance levels and operating parameters have been demonstrated for all the operational states (normal operation, anticipated operational occurrences) and for accident conditions to the extent possible, but not jeopardizing directly or indirectly safety.

2.28. The commissioning programme should be comprehensive, it should include statutory non-nuclear tests in accordance with national practice, and it should have sufficient scope to ensure that there have been no omissions in the testing of complex systems.

2.29. For multiunit plants, the following provisions should be applied:

- (a) Separate commissioning programmes should be prepared and implemented for each unit; even if the systems at a multi-unit site have the same design, the commissioning tests should be performed with the same scope at each unit.
- (b) Some structures, systems and components may be common to more than one unit. In this case, tests should be conducted to provide assurance that the specified performance requirements of such structures, systems and components can be met for the design intent of each unit, and that the design intent is satisfied for each individual unit when all units using such a common system are operational. Tests should also be conducted to provide assurance that the specified performance requirements of such structures, systems and components can be met in cases for which accident conditions in individual units and multiple units can be tested.
- (c) Special provisions, including provision for adequate communications, should be made to ensure that the safety of a unit already in operation is not jeopardized in the commissioning tests for another unit. Such special provisions should include conducting a risk assessment. These special provisions may require obtaining the prior approval of the regulatory body, in accordance with national practices, or obtaining specific approval in writing from the manager responsible for the operating unit.
- (d) A nuclear power plant unit under commissioning should be isolated from areas where construction activities are in progress. Such isolation should protect the unit from events, including possible violations that might occur in construction areas. Likewise, isolation should protect construction areas from possible accidents at a unit under commissioning.

## ROLE OF THE REGULATORY BODY

2.30. The role of the regulatory body in the commissioning process for a nuclear power plant is specified by the responsibilities and functions established by its legal framework and national regulations. The main role of the regulatory body in the commissioning process (including the preparations for commissioning) is the oversight of commissioning activities, including where appropriate issuing (or not) relevant authorizations. The purpose of regulatory oversight should be to ensure that the plant is constructed in accordance with the design intent, its licensing base and that the systems and equipment are installed as designed; and to ensure that their functionality as well as the behaviour of the plant as a whole demonstrates compliance with the design intent and the safety requirements, and demonstrates that the power plant can be operated safely.

2.31. The scope and content of the assessments, reviews and inspections conducted by the regulatory body in connection with the commissioning programme differ from State to State.

In some Member States the regulatory body approves the commissioning programme and establishes the hold points for inspections, review and assessment of the testing results in accordance with the acceptance criteria. An agreement (in some Member States, formal approval) should be obtained before advancing beyond these hold points. The commissioning stages are typical hold points at which the assessment and reviews of the results of commissioning stages are performed before proceeding to the next stage. In particular, such reviews, assessments and inspections, typically for all Member States, are conducted at the stages of fuel loading and of achieving first criticality and power ascension. Ref. [3] provides further guidance on the responsibilities of the regulatory body with respect to the commissioning process.

2.32. In addition to the examination of documentation and the surveillance of tests, there are a number of other areas at which there should be oversight by the regulatory body at the commissioning phase. The ability of the management of the operating organization to progress from supervising construction to supervising operation, and its arrangements for doing so, should also be reviewed. Such a review should cover the management's provision for putting the emergency plan into effect and for the training and qualification of operating personnel. Requirements for the detailed functions and responsibilities of the regulatory body in relation to nuclear power plants are established in Refs [4–7].

2.33. The regulatory body and the operating organization should maintain close liaison throughout the implementation of the entire commissioning programme.

#### ROLE OF THE OPERATING ORGANIZATION

2.34. The operating organization, as the licensee for operation of the plant, bears the overall responsibility for nuclear and radiation safety as well as for protection of workers and the environment and should ensure the correct and satisfactory organization, planning, execution and assessment of commissioning process. See Ref. [8] for further recommendations on the responsibilities of the operating organization.

2.35. Appropriate organizational arrangements should be established to ensure that the operating organization can properly and effectively discharge its responsibilities with regard to the commissioning programme. When commissioning activities are conducted by contractors, the operating organization should make the necessary arrangements to review and approve these activities at all stages, and it should establish appropriate hold points and milestones.

2.36. The operating organization should take appropriate actions during the commissioning phase to ensure that the operating personnel are involved in the commissioning activities as early as possible. Attributes of safety culture such as personal dedication, safety consciousness and a questioning attitude should be fostered in the pre-operational stages so as to become instinctive subsequently for the operational phase.

### 3. ORGANIZATION AND MANAGEMENT OF COMMISSIONING

#### MANAGEMENT SYSTEM FOR COMMISSIONING

3.1. For the commissioning phase, the operating organization should develop and implement a management system that:

- (a) Meets the requirements established in Ref. [9];
- (b) Takes into account the generic recommendations provided in Refs [10, 11].

3.2. The recommendations in paras 3.1–3.12 provide a means of meeting the requirements established in Ref. [9] in the commissioning of nuclear power plants. They are supplementary to, and should be followed in conjunction with, the recommendations provided in Refs [10, 11]. The management system should be consistent with Refs [9, 10] and with Ref. [11], which covers processes applicable to commissioning. The management system should ensure that nuclear safety matters are not dealt with in isolation during commissioning but are considered in the context of all commissioning activities.

3.3. The operating organization (licensee) should develop and implement a management system that describes the overall arrangements for the management, performance and assessment of activities at the nuclear power plant during commissioning. The management system should cover all the activities that are carried out in or necessary for the commissioning phase.

3.4. The management system for commissioning should be established early before the start of commissioning. The system should cover all items, services and processes relating to commissioning, including those important to safety. In establishing and implementing the management system for commissioning, a graded approach based on the relative importance to safety of each item or process should be used.

3.5. The following topics applicable to safety in commissioning should be addressed in the management system:

- Control of documents;
- Control of products;
- Measuring and testing equipment;
- Control of records;
- Purchasing;
- Communication;
- Managing organizational change;
- Project management;
- Work planning and control;
- Risk assessment for the work place;
- Personnel protection and safety
- Control and supervision of contractors;
- Design of structures, systems and components
- Configuration management;
- Plant modification;

- Maintenance;
- Housekeeping and cleanliness;
- Handling and storage of items
- Inventory management;
- Identification and labeling of structures, systems and components;
- Management of spent fuel and radioactive waste;
- Protection of the environment;
- Interfaces with the regulatory body
- Information technology;
- Training;
- Protection against fires and internal flooding;
- Accounting for and control of nuclear material and radioactive material.

3.6. Systems, structures and components are classified in the design phase on the basis of their importance to safety. The classification provides an input in determining commissioning requirements, and requirements for methods, testing, inspections, reviews, qualification of personnel and records.

3.7. The structure, content, extent and means of control of commissioning documents, including their verification and approval, should be described in the management system of the operating organization.

3.8. A key objective of the management system during commissioning is to ensure that the nuclear power plant meets the requirements for safety as derived from:

- The requirements of the regulatory body;
- Design requirements and assumptions;
- The safety analysis report;
- Operational limits and conditions;
- The administrative requirements established by the management of the operating organization (licensee).

3.9. The management system should support the development, implementation and enhancement of a safety culture in all commissioning activities, including among members of the construction, commissioning and operating groups as well as other participants (designers, manufacturers, technical support organizations and contractors). This safety culture and safety awareness should be ensured through appropriate training, highlighting the role and the safety significance of the components concerned. Every person participating in the commissioning activities needs to understand the safety significance of his / her work, to promote personal responsibility.

The commissioning phase should foster a safety culture which should be maintained throughout the operating phase.

3.10. The operating organization should implement adequate arrangements in a management system to ensure quality for a commissioning programme that is effective and is in accordance with national and international standards. Provision should be made to ensure that the quality requirements for commissioning are met by all organizations participating in commissioning activities, including contractors.

3.11. The operating organization should ensure that appropriate procedures are established for the control of commissioning activities at the site to ensure that the commissioning of the plant fulfills the requirements of the commissioning programme.

3.12. Arrangements should be made for adequate and, where necessary, independent oversight and control of the quality of ongoing works.

#### ORGANIZATIONAL ARRANGEMENTS FOR COMMISSIONING

3.13. Organizational arrangements should be put in place to achieve the safety objectives of commissioning in accordance with the commissioning programme. These organizational arrangements should represent a convenient and practical working scheme that allows the optimum use of the available personnel, resources and methods, and which provides assurances on safety.

3.14. The principal activities performed in commissioning may be divided into the following categories:

- (a) Those associated with the final stage of construction of the plant and installation of the plant equipment;
- (b) Those specific to commissioning, including activities for testing and activities for safety review;
- (c) Those associated with the operation and maintenance of the plant.

Accordingly, personnel performing the above activities may belong to the following groups:

- Construction group;
- Commissioning group;
- Operating group;

There may be other representatives participating in commissioning activities, such as designers, manufacturers and technical support organizations. These representatives should collaborate with the aforementioned groups as appropriate. In particular, designers and manufacturers should provide adequate and complete information to the groups. The designers should also review the commissioning data, and should where necessary be involved in the resolution of problems and the rectification of defects detected during the commissioning stage.

3.15. There may be many ways in which the construction, commissioning and operating groups could be formed. This may depend upon the industrial practice and the experience of nuclear power in the Member State, and upon contractual arrangements, as well as upon the physical size and design of the plant. The composition of the groups may also be influenced by the availability and experience of personnel performing specialized functions. If the operating organization decides to subcontract the commissioning activities to another organization, it should be made clear that the ultimate responsibility for commissioning and for safety remains with the operating organization.

3.16. The working arrangements should, as far as practicable, make use of the operating personnel so that they become familiar with the plant and the facilities during commissioning. In addition, the operating group should participate in the commissioning activities from the

start of the commissioning process to ensure that as many operating personnel as possible gain field experience and to establish an 'institutional memory' of the plant.

3.17. The management system should ensure that the responsibilities remain clear at all times even if construction, commissioning and operating activities overlap.

3.18. In all the cases, under the overall direction of the operating organization as licensee:

- the construction group should ensure that structures, systems and components are properly constructed and installed in accordance with the design, and that the requirements for quality management have been adhered to during construction;
- the commissioning group should ensure that structures, systems and components are tested to provide assurance that the plant has been properly designed and constructed and is ready for safe operation;
- the operating group should operate systems and equipment in accordance with the assumptions and intent of the commissioning programme, respecting the relevant operating limits and conditions that are applicable for each testing stage [12].

## **Operating organization**

### *Establishing the operating group*

3.19. The operating organization should establish an operating group at the plant to take over the responsibilities that are transferred from the construction group and the commissioning group for operation of the equipment and systems. The operating group, on behalf of the operating organization, should take over from the construction and commissioning groups the responsibilities for the equipment and systems and should ensure their safe functioning and maintenance. The operating group should be established at the early stages of construction of the nuclear power plant to give it time for familiarization with the structures, systems and components of the plant and with the preparations for taking over the operating functions for the equipment and systems and for the plant as a whole.

3.20. The operating group should be composed of personnel of different disciplines, and it should include formally authorized (if necessary licensed) control room operators who have passed through an adequate training and authorization procedure.

3.21. The operating group should in all its activities be under the control of the operating organization and accountable to the operating organization.

3.22. The responsibilities of the operating organization should include the following:

- To control, review and coordinate the activities of the construction, commissioning and operating groups in an effective manner;
- To ensure that the activities of the construction and commissioning groups are properly managed, and that any issues are dealt with to meet the requirements for safety;
- To ensure that the commissioning procedures are prepared, reviewed and approved;



- To communicate with, and to arrange for the required submissions to, the regulatory body, in accordance with national regulations and practices;
- To ensure that agreed procedures are established for coordination and management of activities in the commissioning phase including procedures for the specification of responsibilities and the interfaces between them, and for their transfer of at given milestones (these procedures should take into account the views and experience of members of the construction, commissioning and operating groups as well as other participants: designers, manufacturers and technical support organizations);
- To ensure that construction, commissioning and operating groups maintain adequate numbers of properly trained, experienced, qualified and, where required, authorized personnel;
- To receive and disseminate the requirements of and information from the regulatory body;
- To ensure that the documentation of the plant is kept up to date during the commissioning process (configuration control) and that all parties involved in the commissioning process have access to the current documentation and information;
- To collect information on all equipment in order to establish a base line to be used for the monitoring of the performance of equipment throughout the service life of the equipment;
- To respond to and manage an emergency in the commissioning phase and to implement appropriate emergency arrangements as given in greater detail in the section on emergency arrangements.

3.23. In discharging these responsibilities, various methods may be adopted by the management of the operating organization. The essential tasks in achieving the necessary coordination are as follows:

- To review and approve the commissioning programme;
- To ensure that adequate provision is made to ensure the availability of necessary resources (personnel, support systems, resources for use in an emergency, information and knowledge, resources for the working environment, infrastructure, financing and materials) for commissioning;
- To make available, from the start of the commissioning phase, operating staff, maintenance staff and technical staff for the purpose of their familiarization with the operation and management of the plant;
- To specify and to monitor the transfers of responsibilities for SSCs;
- To monitor the implementation of the commissioning programme;
- To resolve any problems between groups and any other interface problems;
- To review and approve test procedures;
- To consider the safety aspects of commissioning procedures and of proposed changes to them in order to validate the commissioning procedures and the proposed changes in the light of their compliance with operating requirements (requirements for nuclear safety, technical specifications, requirements for plant chemistry, etc.);
- To determine whether tests and stages have been properly completed;
- To monitor the rectification of those defects or deviations detected during the commissioning phase to ensure that the defects and deviations are rectified in the

light of their potential impacts on plant safety, performance and operational effectiveness;

- To maintain liaison with the regulatory body in accordance with national regulations and national practice.

#### *Organization of the commissioning group*

3.24. The commissioning group and the special arrangements to ensure the proper coordination and performance of commissioning activities in the commissioning phase should be established early enough to allow all of the necessary activities to be identified and adequate preparations to be made.

3.25. The commissioning group should be headed by a commissioning manager who has relevant experience and qualifications. The commissioning manager should be appointed well in advance of the actual commissioning activities so as to be able to make the necessary arrangements for scheduling and organizing work units, work plans and other resources.

3.26. Specific test teams should be established to perform commissioning tests. The number and composition of these teams should be dependent on aspects such as the following:

- The number and complexity of the systems to be tested;
- The scheduled target dates;
- The workload;
- The skills necessary to perform the tests;
- The number, complexity and safety significance of the systems to be tested.

3.27. Effective coordination of work between test teams should be ensured.

3.28. In addition to the overall commissioning and scheduling, the detailed planning and scheduling function should be managed in the commissioning group.

## **FUNCTIONS AND RESPONSIBILITIES IN COMMISSIONING**

### **General**

3.29. Commissioning activities may be assigned to a contractor, the construction organization or the operating organization. In some cases, responsibility may be transferred from one organization to another at the time of fuel delivery and fuel loading, or at some other appropriate milestone or hold point. Whatever the arrangement, the organization or individual performing commissioning should be accountable to the organization or individual responsible for compliance with the license with regard to the following:

- Demonstrating that the plant behaves in accordance with the design intent;
- Confirming that the plant has been tested within the design limits;
- Ensuring that the commissioning process is conducted in observance of safety requirements.

The operating organization, as licensee, and thus responsible for safety, will be responsible for interfaces with the regulatory body with regard to regulatory requirements.

3.30. A gradual handover of systems and components of the plant between the groups involved in the overall commissioning process should be setup, with a clear specification of the associated transfer of responsibilities, as described in the section on transfer of systems and handover of the plant.

3.31. The detailed listing of functions and responsibilities provided here is illustrative only; actual functional responsibilities may vary according to the national regulations and practice.

### **Construction group**

3.32. The responsibilities of the construction group should include, but are not limited to, the following:

- To ensure that the construction and installation of structures, systems and components have been completed in accordance with design requirements and specifications;
- To inspect and assess settlement and distortion in soil and concrete structures to identify defects that may result from micro-cracks development.
- To make suitable arrangements for surveillance, control and maintenance to prevent deterioration after the completion of installation (or construction) and before the handover;
- To provide, for use as baseline data, as-built documentation of installation and construction and test reports, highlighting design changes and concessions;
- To ensure that configuration control is maintained and that the affected systems design basis documentation, including the final safety analysis report, as required, has been updated to reflect any design changes and/or concessions;
- To ensure field changes to original design specifications consider radiation dose optimization (ALARA), and future maintenance and decommissioning activities.
- To transfer the installed systems to the commissioning group using a system of plant handover documents;
- To ensure the clearance of remaining open points that set conditions on the acceptance of the transfer;
- To rectify deficiencies in construction and installation that are detected in commissioning;
- To assist the commissioning group in resolving construction related issues.

### **Commissioning group**

3.33. The responsibilities of the commissioning group should include, but are not limited to, the following:

- To plan in advance the development of the commissioning programme with detailed test sequences, time schedules and staffing requirements;
- To update the commissioning programme in the light of experience in commissioning and as a result of design modifications;
- To establish a procedure for the preparation, review and approval of test procedures and other procedures;
- To ensure that operational flow sheets, operating and maintenance instructions, commissioning procedures, formats for commissioning reports and test reports,

documents on plant handover and submissions to the regulatory body are available;

- To establish a procedure for the systematic recording of plant data for future use;
- To establish a procedure for ensuring that incidents and other unexpected events during commissioning are dealt with and analysed so that the experience can be fed back to the designers and the operating group;
- To verify that the installation of structures, systems and components has been satisfactorily completed and has been codified for proper identification;
- To ensure that the prerequisites for the commissioning programme have been satisfied and that pre-operational tests such as system flushing, functional checks, logic checks, interlock checks and system integrity checks have been completed;
- To ensure that the commissioning procedures comply with the appropriate rules and regulations and requirements for safety (including those for radiation protection, nuclear safety, fire safety, industrial safety and protection of the environment);
- To provide baseline radiological background conditions at commissioning of a plant, and establish a related record keeping system.
- To ensure that the systems are commissioned safely and to confirm that the written operating procedures are adequate;
- To implement all tests in the commissioning programme, including repeat testing of the systems that have been commissioned initially as partially installed;
- To make suitable arrangements for testing and maintaining systems (particularly safety related systems) for which responsibility has been accepted;
- To direct the operation of systems in the commissioning programme and to provide inputs for updating operational flow sheets, operating and maintenance instructions and procedures on the basis of commissioning experience;
- To issue commissioning reports on tests;
- To ensure that the results of safety related test have been approved by the regulatory body, if necessary;
- To ensure that a process is in place to control the calibration of test and measurement equipment;
- To ensure that all participants in the commissioning process have suitable qualifications and experience;
- To ensure the configuration control, maintaining consistency between the physical state of the plant and the test procedures and design requirements (any discrepancy should be reported to the relevant parties to ensure that design changes are requested, reviewed, effected, and retested when design criteria are not met or when the changes effected fall short of the design changes requested);
- To establish and implement a system for controlling, recording and communicating temporary changes to the plant and equipment;
- To issue test certificates and stage completion certificates or their equivalent;
- To provide up to date baseline information to the operating group and the operating organization;
- To report to the operating organization any deficiencies detected in commissioning tests in order that corrective actions can be taken;
- To maintain a record of limiting conditions in commissioning and to ensure that tests to be performed do not lead to these conditions being exceeded;

- To ensure that plant performance is in accordance with the design intent, including all aspects of radiation protection, nuclear safety, fire safety, industrial safety and protection of the environment;
- To document that the commissioning programme has been satisfactorily completed;
- To transfer the responsibility for operation and maintenance for commissioned systems and/or for the plant to the operating group using a system of relevant documents;
- To establish and implement procedures to ensure the orderly transfer of responsibilities for structures, systems and components from the construction group to the commissioning group and from the commissioning group to the operating group;
- To ensure that an opportunity is provided for operating personnel to gain experience at the plant, typically by utilizing the appropriate personnel, as necessary, for commissioning activities;
- To establish procedures for analysing the results of tests;
- To ensure that any deviations detected are recorded, rectified and documented;
- To record all the feedback of experience from commissioning;
- To establish a procedure to compile the lessons learned from commissioning activities, to draw conclusions and to determine the necessary corrective actions.

### **Operating group**

3.34. The responsibilities of the operating group should include, but are not limited to, the following:

- To participate as early as possible in the commissioning activities;
- To satisfy itself that the systems that are transferred comply with specified performance requirements, the design intent, safety requirements and regulatory requirements;
- To accept responsibility (for operation, maintenance and safety as per the operational limits and conditions) for the transferred systems;
- To increase competence in the methods of operation of the plant;
- To carry out operation and maintenance with competent and duly authorized staff using approved techniques to meet the needs of the commissioning programme;
- To establish and implement a procedure for the systematic recording of plant data from commissioning tests;
- To establish and implement arrangements, including organizational responsibility, to maintain plant design and configuration control over the commissioning phase up until the start of the operating lifetime of the plant (this includes maintaining the safety analysis report current);
- To participate in a safety assessment when necessary;
- To assist with design modifications in order to rectify design deficiencies and to provide complete documentation of the modifications, including requalification tests and to approve modifications;
- To record all the feedback of operating experience and the associated lessons to be learned;
- To establish and implement appropriate emergency arrangements.

### **Other participants in the commissioning activities**

3.35. The responsibilities of the other participants, such as designers, manufacturers and supporting technical organizations in the commissioning activities, should be specified in the appropriate contracts. The following responsibilities should be considered:

- To cooperate with relevant parties engaged in commissioning activities as appropriate to provide specialist knowledge, expertise and relevant experience from plants already commissioned;
- To provide support for the evaluation and assessment of tests results, including any deviations;
- To provide baseline data and all necessary information;
- To provide a safety assessment when necessary;
- To participate in the analysis of discrepancies and unexpected events;
- To design modifications to rectify design deficiencies and to provide complete documentation of the modification, including documentation of requalification tests.

### **INTERFACES IN COMMISSIONING**

3.36. Many other activities are performed in parallel with the commissioning of the plant, such as activities relating to construction, operation and maintenance.

3.37. The interface between these activities should be adequately managed to ensure the safety of the plant and the protection of personnel and to allow for an adequate commissioning programme.

3.38. The interrelationships between tests, between systems and between units on the same site should be considered.

3.39. Appropriate work control processes 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 processes should provide for the proper channelling of the work to the persons responsible for the systems and for ensuring notification and awareness by the control room operators of all the work activities that are in progress.

3.40. Clear and well understood lines of authorization and communication between the different groups involved in construction and commissioning activities should be established and documented. The lines of communication should support the commissioning schedule and should be consistent with the agreement on the scope of activities of all organizations, in particular at the interfaces.

### **Interface between construction activities and commissioning activities**

3.41. The construction group may be the lead group for some activities during the commissioning programme. Where this is the case, it should be specified well in advance of the commencement of this programme in order to avoid misunderstandings.

3.42. The following interfaces in particular between construction activities and commissioning activities should be considered:

- Procedures for transferring structures, systems and components from construction to commissioning;
- Procedures for isolation of parts of the plant transferred to commissioning from the parts remaining under construction;
- Prerequisites for the start of the commissioning programme and for the start of commissioning of systems;
- Special precautions necessary for the commissioning of partly installed systems;
- Procedures for the performance of works on systems under commissioning.

3.43. Specific attention should be paid to systems that have been partially installed and, as a consequence, have been only partially commissioned. Commissioning tests should be designed and implemented to allow for adequate commissioning of the full system.

#### **Interface between commissioning activities and operating activities**

3.44. The following interfaces in particular between commissioning activities and operating activities should be considered:

- Provisions in the specification of the role, functions and delineation of responsibilities of the operating group and the commissioning group before the transfer of structures, systems and components for operation;
- Procedures for the transfer of structures, systems and components for operation;
- Methods of identifying special technical, operational or staffing restrictions necessary as a result of the partial completion of a construction activity or a commissioning activity;
- Baseline data derived from commissioning, such as the issuing of formal test reports and a statement of the existing radiological conditions;
- Changes in responsibility for safety, depending on milestones commissioning that are considered and the transfers to operation that are performed, including the nomination of responsible persons;
- Modifications to the plant and to the procedures;
- Availability of as-built drawings, instructions and procedures for operating and maintaining the systems and the plant;
- Conditions for access of personnel, with account taken of the delineation between systems already in operation and systems being tested;
- Control of temporary procedures and equipment that are available during commissioning but not appropriate to normal operation; for example, special startup instrumentation or duplicate safety keys and authorization for the use of jump and lifted leads.
- The implementation of operating requirements and maintenance requirements for structures, systems and components as each system is transferred to the operating group;
- Provision of sufficient opportunity for the operating personnel to become trained in and familiar with operating techniques and maintenance techniques for the plant;
- Procedures for mapping of radiation controlled areas and workplace monitoring and personnel monitoring, including recording of doses to personnel and training in radiation protection and safety, and authorization of personnel conducting commissioning activities to work in the radiation controlled areas;

- Procedures for effluent discharges and keeping records of waste generated and radionuclide releases.
- Reassessment of instructions and procedures for routine operation and maintenance in the light of experience gained in commissioning;
- Development and implementation of measures for emergency preparedness and response;
- Keeping records during commissioning of information that could have implications for future decommissioning and the subsequent handover of these records to the operating organization (examples are records of spills or other unusual occurrences that could have long term effects).

3.45. There should be plans to include operating personnel in commissioning activities at all levels at the plant, thus providing the operating staff with an opportunity to become familiar with, and to gain valuable experience for, operation of the plant.

3.46. Procedures for operating and periodic testing should be used as far as the conditions at the plant will allow in the commissioning phase so as to validate them eventually with success criteria more numerous or more challenging than the ones to be used during operation. Inter-organizational arrangements should be made to schedule this activity so as to ensure that procedures, including operating, maintenance and surveillance procedures, are adequately validated.

3.47. Personnel should adhere to normal operating rules such as those relating to 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.

### **Interface with the regulatory body**

3.48. Before authorizing significant steps such as introduction of nuclear or certain types of radioactive material, the loading of nuclear fuel and initial criticality, the regulatory body should complete as appropriate the review, assessment and inspection of such aspects as:

- The draft of the (provisional) final safety analysis report;
- The as-built design of the plant;
- The results of pre-operational tests;
- The operational limits and conditions;
- The specific operational limits and conditions for operation during the commissioning of the plant from first criticality to full power;
- The adequacy of safety significant operating procedures and instructions, including emergency operating procedures and accident management procedures;
- The staffing and management structure of the plant and arrangements for ensuring that qualification and training are performed;
- The arrangements for quality management for all commissioning, operation and maintenance activities;
- The records and reporting system;
- The radiation protection programme;
- On-site emergency preparedness and response;



- The arrangements for commissioning activities and operational activities (including, maintenance, surveillance, inspection and periodic testing);
- The arrangements for configuration control, especially control of plant modifications;
- The arrangements for the management of spent fuel and radioactive waste;
- The status of storage facilities for nuclear material;
- The fulfilment of the applicable requirements in respect of arrangements for accounting for and control of nuclear material and radioactive material.

3.49. Before the authorization of routine operation at full power, the regulatory body should complete the review and assessment of:

- The results of commissioning tests and their analysis;
- The updated final safety analysis report and updated operational limits and conditions;
- The updated as-built modifications to the plant that were made during commissioning.

#### TRANSFER OF SYSTEMS AND HANDOVER OF THE PLANT IN COMMISSIONING

3.50. 'Handover' of the plant is the transfer of responsibilities for the plant. This should include the transfer of responsibilities for structures, systems and components, items of equipment and documentation, and it may include the transfer of personnel. The procedures for handover of the plant should be in compliance with the national regulations applicable to operating organizations. Depending on the plant organization and the framework for handover, two separate types of transfers may take place; one from the construction group to the operating group directly, and the other from the construction group to the commissioning group and finally to the operating group. All of these transferal activities should be documented.

3.51. The operating organization should ensure that an appropriate procedure for the handover of the plant is in place. The provisions describing the detailed steps in the process for handover, including the responsibilities and authorities of the parties involved, should be presented in this procedure.

3.52. Before the introduction of nuclear material and radioactive material (the 'pre-nuclear' phase) in the commissioning programme, the responsibility for systems should gradually be transferred to the operating group as soon as the testing has been performed and the results have been reviewed and found satisfactory. Before the start of nuclear testing, all the systems should be under the control of the operating group.

3.53. The transfer of documentation is a key feature in the handover process. Documentation should be transferred in acceptance packages corresponding to different systems and should be transferred over a reasonable period of time.

3.54. The following documentation should be included in the acceptance package for each system:

- General correspondence and system records;
- Results of load tests and pressure tests, and flushing and cleaning records;

- Acceptance packages from construction (including records of welding inspections);
- As-built diagrams, electrical diagrams, instrumentation and control diagrams, flow diagrams;
- Documentation of ‘pre-nuclear’ test procedures and report data sheets;
- Failure reports and incident reports;
- Documentation on temporary modifications, lifted leads and jump leads, and records of software modifications;
- Equipment isolation records and records of work permits;
- Records of preventive maintenance and corrective maintenance;
- Surveillance records;
- Records of design changes;
- Lists of pending items, including defects, omissions and weaknesses carried forward from the previous handover;
- Statutory certificates;
- Operating procedures and maintenance procedures;
- Vendors’ manuals and set point books;
- Manufacturers’ documents indicating tests conducted and quality management aspects covered in manufacturing.

3.55. Suitably qualified personnel should be designated to conduct the review to be carried out by the operating organization receiving the handover package. In performing the review, plant walk-downs should be carried out by representatives of the organizations involved in the handover process and meetings should be held between these organizations as necessary.

## RESOURCES FOR COMMISSIONING

### Provision of resources

3.56. It is stated in Ref. [10] (paras 4.1 and 4.2) that:

“Senior management shall determine the amount of resources necessary and shall provide the resources<sup>1</sup> to carry out the activities of the organization and to establish, implement, assess and continually improve the management system.”

“The information and knowledge of the organization shall be managed as a resource.”

3.57. The operating organization should have a process in place for planning human resources to ensure the adequacy of the organization during commissioning. This includes planning of the organization and raising the competence of the staff during commissioning. Adequacy of organization and staff competence should be assessed on a continuous basis.

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<sup>1</sup> ‘Resources’ includes individuals, infrastructure, the working environment, information and knowledge, and suppliers, as well as material and financial resources.

3.58. The operating organization should have a systematic approach to monitoring and supervising the adequacy of contractors' resources and their competence.

3.59. Resources necessary to carry out the commissioning activities, such as tools, and utilities and logistics should be planned for. For example, the amount of demineralized water necessary for the flushing of installed components and the stable electric power sources necessary for the commissioning of structures, systems and components important to safety should be determined and provided for.

#### QUALIFICATION AND TRAINING FOR COMMISSIONING

3.60. Personnel engaged in commissioning activities should be suitably qualified and experienced for the level of responsibility and for the importance to safety of their work. The necessary level of qualification and experience should be specified for each position in the organization. Training of personnel who participate in the commissioning process should cover relevant aspects of the plant site and methods of working.

3.61. A training programme should be developed to cover these aspects of the plant site and methods of working. The subjects that should be included are:

- Systems of the nuclear power plant;
- Formal commissioning procedures
- Conduct of testing and maintaining the plant in safe conditions;
- Procedural changes and design changes;
- Permanent and temporary modifications;
- Work control and equipment isolation;
- Interfaces of construction, design and operation with commissioning;
- Test limitation boundaries in mechanical and electrical systems;
- The criteria for and the importance of reporting incidents and deviations;
- Methods of and techniques for commissioning;
- Safety culture;
- Nuclear safety, industrial safety, fire safety and radiation protection;
- Design criteria, technology and operational limits and conditions (or the equivalent) for the plant;
- Management of spent fuel and radioactive waste;
- Protection of the environment.

Operators should be trained at a full scope simulator for starting up the reactor, regular operations, shutting down and cooling down of the reactor, and dealing with various transients and accident conditions..

3.62. The training programme and trainees should be subject to periodic assessment, the results of which should be passed on to the commissioning manager and supervisors. The regulatory body may have a role in reviewing and approving the training program, as defined by national regulation.

3.63. As a part of safety culture, construction and commissioning personnel should understand their functions in establishing a sound basis for the subsequent operation and eventual decommissioning of a plant.

3.64. If any major incidents occur during commissioning, training should be systematically reassessed. Experience gained in commissioning should be appropriately incorporated into the training material. Objectives of quality and safety should be emphasized.

3.65. Recommendations and guidance on the qualification and training of commissioning personnel, particularly those involved in the commissioning of safety related systems, are presented in Ref. [13].

#### MEASUREMENT, ASSESSMENT AND IMPROVEMENT

3.66. The management system for commissioning should allow for monitoring and measuring the effectiveness of the management system itself, and to ensure that it is continuously improved.

##### **Management of non-conformances**

3.67. The provision of a consistent process for the management of non-conformances is a requirement of all management systems. The process for the management of non-conformances should apply to the failure of components to meet their specified performance requirements and the failure of larger systems to meet their requirements on the basis of the safety analysis or other performance specifications. A robust system for recording and resolving non-conformance and for approving concessions, corrective actions and preventive actions should be in place. See also Refs [10] and [11].

##### **Feedback of experience from commissioning**

3.68. The commissioning phase yields much information that should be taken into account in the subsequent operation of the plant. Proper systems should be established for reporting on and analysing abnormal events, human errors and 'near misses' that occur in the commissioning phase. Experience gained at this stage should be fed back into the training programmes for operating personnel and commissioning personnel. The lessons to be learned should be used in the improvement and development of the commissioning programme, in operating procedures and instructions, and in maintaining configuration control of the simulator and training material. Available information on operating experience, including reportable occurrences at operating power reactors, should be used appropriately in developing and executing the test procedure. Consideration should also be given to the need for any changes in the design and in the related documents.

3.69. In the preparation of the commissioning programme, consideration should be given to experience gained around the world and to information available in the nuclear industry as well as in other industries.

#### MAINTENANCE DURING COMMISSIONING

3.70. From construction to commissioning and finally to operation, the plant should be adequately monitored and maintained. The plant should be subject to the inspection and required periodic testing in order to protect equipment, to support the testing stage and to continue to comply with the safety analysis report and operational limits and conditions.

Historical records should be kept of operation and maintenance in the commissioning phase from the time of the initial energization and operation of the equipment of each plant system. Provision should be made to transfer these records to the operating organization eventually.

3.71. The organization for maintenance during commissioning should be adequately described and documented so as to be clear to all parties involved. Recommendations and guidance on maintenance activities are provided in Ref. [14].

#### ARRANGEMENTS FOR EMERGENCY PREPAREDNESS AND RESPONSE IN COMMISSIONING

3.72. The operating organization should be responsible for ensuring that an appropriate emergency plan is put in place for preparedness for, and response to, an emergency in the commissioning phase. Appropriate emergency response arrangements should be established before nuclear fuel is brought onto the site. Complete emergency response arrangements should be put in place and should be tested before the commencement of fuel loading.

3.73. In preparing emergency response arrangements for the commissioning phase, account should be taken of the fact that construction related hazards may still exist.

3.74. A potential nuclear hazard could arise if an operating plant is adjacent to a construction site or a commissioning site. If this is the case, emergency response arrangements should be made for the protection of construction personnel and commissioning personnel. Any other local hazards should be taken into account in the emergency response arrangements.

3.75. All the parties involved in the commissioning programme should be appropriately trained to respond to a possible emergency at the plant during commissioning.

3.76. Requirements on detailed instructions and procedures for actions to be taken in the event of a nuclear or radiological emergency are established in Ref. [15].

#### MANAGEMENT OF UNEXPECTED EVENTS IN COMMISSIONING

3.77. Commissioning activities, including the commissioning tests, should be planned and performed within the operational limits and conditions derived from the safety analysis report. However, faults may occur, and for each test procedure consideration should be given to any fault responses and contingency actions required. In some cases, these responses and actions may be the same responses to alarms that will be necessary for planned operation. In other cases, however, specific actions will be required, owing to the configuration of the plant during testing. The test procedures should identify the specific limits and conditions applicable to the test and the actions to be taken if the limits are approached.

### **4. IMPLEMENTATION OF THE COMMISSIONING PROGRAMME**

4.1. For implementation of commissioning activities some personnel may need to be formally authorized (if necessary licensed) in accordance with national regulations.

4.2. The commissioning programme should be implemented in stages and sub-stages in accordance with the text on the stages of commissioning (see paras 2.17–2.22) and on testing stages and sequences (see para. 4.28–4.60)

4.3. The commissioning programme should be implemented in accordance with the requirements of the management system of the licensee. To this end, all contractors involved in the commissioning process should ensure that their own arrangements meet the requirements of the management system of the licensee.

4.4. There could be tests performed off-site on structures, systems and components that need to be considered as part of the commissioning process. In such cases, specific justification should be provided to show the validity of the tests performed for the current as-installed conditions of the structures, systems and components and for the related functional and physical interfaces.

4.5. The commissioning process should be documented in compliance with the management system of the operating organization. The documentation showing the testing and results, analysis, deviations and dispositions should be kept by the operating organization for the lifetime of the nuclear power plant.

4.6. The design, operational and safety documentation for the nuclear power plant should be updated during the commissioning process in accordance with the test results and the resolution of deviations.

## COMMISSIONING TESTS

### **Purpose and objectives of the commissioning tests**

4.7. The preparatory process for testing should clearly identify the purpose and the objectives of the commissioning tests from the commissioning test programme, with particular focus on the safety objectives. The safety objectives should be clearly put in evidence and should be linked with safety criteria and characteristics mentioned in the (preliminary) safety analysis report.

### **Scope and methods of the test**

4.8. The scope of the test in terms of functions, parameters and requirements to be tested should be specified, with an indication of the approach and the methods applied for each relevant aspect. If the testing procedure will make use of the results of in-factory tests that have already been performed, this should be stated and justified. The justification should show the validity of the factory tests already performed and their applicability for the physical and functional status of equipment or systems on the site that are subject to the tests and their interfaces with the rest of the nuclear power plant. If first-of-a-kind, that is, new, unique, or special, principal design features will be used in the nuclear power plant, the in-plant functional testing requirements necessary to verify their performance should be identified at an early date to permit these test requirements to be appropriately accounted for in the final test design.

## **Acceptance criteria**

4.9. The acceptance criteria should be clearly specified in the testing procedure, with account taken of potential uncertainties in measurements. The technical basis of the acceptance criteria should be consistent with the safety objectives and requirements, the design intent and the results of previous testing.

4.10 The acceptance criteria should be linked to the expectations, performance and requirements for safety and/or design. Acceptance criteria should be grouped into categories on the basis of their importance to safety. At least two categories should be specified:

- Acceptance criteria for safety requirements;
- Acceptance criteria for non-safety aspects.

4.11 The safety acceptance criteria should be specified and justified to ensure that they do demonstrate the achievement of test objectives for safety. This specification and justification should take into account the limitation of achieving site specific conditions without impairing the integrity of the plant, structures or equipment. The specification and justification of acceptance criteria should establish a link between the safety requirements to be demonstrated and the parameters measured during the test. The adequacy of the acceptance criteria should be documented in the test documentation. In cases, where safety requirements are verified by calculation, the computer code or simulation tools should undergo verification and validation.

4.12. A list of the acceptance criteria that are to be verified, notably the acceptance criteria linked to safety requirements, should be made available at the end of each commissioning stage or sub-stage. The list should highlight those acceptance criteria that will have to be changed because they could not be met. A process to review and authorize these acceptance criteria to be changed should be put in place. This represents one of the main inputs into the assessment of the ability to proceed to further commissioning stages.

## **PREPARATION FOR TESTING**

### **Commissioning documentation**

4.13. All commissioning tests should be performed in accordance with written test programmes and procedures as stated in Section 5, para. 5.11 on documentation, commissioning programmes and procedures. The preparation of these test procedures, including their verification and approval, should be implemented in accordance with the management system. The level of review should reflect the importance to safety of the system and the nature of the document and of the test. The test documents that are established should allow commissioning to proceed safely and efficiently.

4.14. The commissioning programmes should present the objectives and principles of commissioning in relation to the entire plant, the different systems and the different stages:

- General presentation of the commissioning programme and stages of the entire plant;
- Description of the test objectives, principles, acceptance criteria and sequencing for each system;

- Specification of the prior conditions and the list and chronology of tests and activities to be carried out during each commissioning stage.

4.15. The test procedures should specify in detail how each item of equipment or system or component will be commissioned. The procedures will thus form the core of the commissioning process. Competent personnel and adequate controls should therefore be put in place to ensure that the test procedures are safe and of a high standard.

4.16. The test procedures should be subject to a thorough verification that involves the operating organization. The designers and the regulatory body, if necessary, should also participate in the approval process, and in particular in reviewing the validity of the acceptance criteria.

4.17. The test procedures should follow normal plant operating procedures, covering the operational states (normal operation, anticipated operational occurrences) and accident conditions, to the extent practicable, so as to verify them. If necessary, the normal operating procedures should be amended for use during commissioning. Such amendments should be reviewed, authorized and recorded.

4.18. A simulator or computer codes should be used in the development, verification and validation of commissioning test procedures, if possible. A simulator should be used for preparation on specific relevant aspects by the team implementing the commissioning tests.

4.19. The test procedures should state necessary deviations and/or changes from the normal plant operating configurations and the associated compensatory measures (if any). Examples of such deviations and/or changes may be temporary interlock bypasses, temporary additional interlocks, temporary system bypasses, valve configurations and instrument settings. The test procedures should include all the checks that are necessary to ensure that these deviations and their associated compensatory measures are implemented correctly. They should also include all necessary steps for the restoration of the systems and components to their normal status once the testing has been completed. Consistent with safety requirements, consideration should be given to minimizing such arrangements and to ensuring that any deviations from the normal functioning of the as-built systems do not invalidate the test objectives nor compromises safety.

4.20. Techniques and methods of data analysis, including the analysis of measurement results, should be presented in the test procedure. Uncertainties in measurements should be taken into account in comparing the results with the acceptance criteria.

#### **Equipment and measurement tools for testing**

4.21. In order to comply with the testing procedures, various precision tools, calibrated tools, and measuring and test equipment should be used to ensure that structures, system and components conform to the design. This measuring and test equipment should be periodically calibrated in order to achieve and maintain the level of precision adequate to the testing requirements. Where a testing process, or a sequence of testing processes, requires calibrated tools or equipment to be used to determine conformance to the specifications of the systems, structures and components for certification for release to service, calibrated equipment should be used at each step in the process.



4.22. The register of the measuring and test equipment should be established for the equipment currently in use by the commissioning organization. The register should identify the equipment by means that can be related to actual markings on the equipment itself.

4.23. The management system should include details of the maintenance and calibration of measuring and test equipment.

4.24. The management system should to ensure that the calibration intervals are not exceeded for the testing equipment and measurement tools and to ensure that any new testing equipment and measurement tools are obtained with the appropriate calibration certificate. All individual users of instruments should verify that the measuring and testing equipment is in good condition and that the calibration status is adequate before the beginning of tests.

#### PREREQUISITES FOR TESTING

4.25. Before the start of a test of a structure, system or component, certain other activities should first be performed and completed, such as construction and/or preliminary tests, inspections and certain other pre-operational tests or operations. The typical prerequisites for the testing are as follows:

- Construction and installation activities associated with the system to be tested have been completed and documented;
- Tests of individual components or subsystems to demonstrate that they meet their functional requirements have been completed;
- Checking out of the continuity of wiring and of electrical protective devices, adjustment of settings on torque limiting devices and calibration of instruments have been completed;
- All special conditions, including chemical conditions, for the plant or system or for the necessary status of equipment prior to the commencement of testing using the procedure have been effected;
- All necessary jumpers and interlocks are installed for the particular testing configuration;
- Procedures are approved and personnel are trained;
- The personnel required are available and briefing is complete;
- Testing and measuring devices are adjusted, calibrated and checked;
- Field inspections have been made to ensure that the equipment is ready for testing, including inspection for proper fabrication and cleanliness;
- Communication tools are available and have been checked for operability;
- Written authorization, if required, has been issued prior to the commencement of the test or the commissioning stage;
- All documentation showing readiness for the test to be performed has been issued and approved and the necessary documentation is available;
- Safety analysis of the conditions at the nuclear power plant during the test to be performed has been carried out in advance and shows that the conditions during the performance of the test are acceptable for safety;
- The conditions to ensure proper configuration of the system after testing have been identified;
- The conditions to ensure the conservation of equipment after its testing have been determined and implemented;

- There is compliance with the authorization corresponding to what was envisaged in the commissioning programme, to the hold points established by the regulatory body and also to specific conditions issued by the regulatory body in accordance with national practices.

4.26. The starting of a commissioning stage or sub-stage, as described in the commissioning programme, should be based on the completion of the previous stage and the fulfilment of conditions specified in advance. For instance, the pre-operational tests should be completed and the results of such tests should be evaluated and approved before proceeding to fuel loading and subcritical tests.

4.27. Administrative controls should be established to ensure that activities are started or performed as required on the basis of the programmes, in a specified sequence and in accordance with requests or constraints imposed by the parties involved (i.e. the commissioning organization, the operating organization, the regulatory body and other parties as envisaged).

## TESTING STAGES AND SEQUENCES

4.28. In determining the sequence of testing, the following four points should be considered:

- (1) The sequence of commissioning tests should be planned in the chronological order in which they are expected to be performed and the systems required to ensure nuclear safety in the commissioning stage should be adequately tested prior to the testing of integrated systems;
- (2) Certain specific support systems (e.g. Compressed air system, electrical system, service water system, system for supply of demineralized water, system for the management of radioactive waste, ventilation system, drainage system) should be commissioned prior to other systems so that they are available for the testing of other systems;
- (3) Certain specific systems should be operational to ensure that other systems can be tested without jeopardizing personnel, the plant or nuclear safety (e.g. Fire protection systems, radiation protection systems, emergency power system, system for the management of radioactive waste);
- (4) At any given stage, the corresponding tests to be performed should be grouped together and should be completed before the commissioning programme can be safely continued.

### **Pre-operational tests**

4.29. Before the commencement of the initial testing of any structure, system or component:

- (1) Construction activities associated with the system, including quality management checks and documentation, should be completed, documented and reviewed;
- (2) It should be ensured that the equipment is ready for commissioning as per the prerequisites mentioned in the applicable commissioning procedure;
- (3) It should be ensured that test equipment, instruments and supporting systems to be used during commissioning are appropriate and operable;

(4) It should be ensured that qualified and trained personnel is available.

4.30. A review should therefore be undertaken before the commencement of this stage to ensure that the necessary tests have been carried out on those systems and components that are required for this stage. The tests should ensure that the construction is of the appropriate quality and that the equipment is in a fit state for commissioning to be commenced.

4.31. In a satisfactory pre-operational test, the proper sequence of tests of electrical systems, instrumentation systems, and other service systems such as cooling water systems and fire protection systems should be taken into account to ensure the availability of the necessary services for the entire commissioning programme.

4.32. The stages of the pre-operational tests may be divided into the following sub-stages:

- Cold performance tests; and
- Hot performance tests.

Any required pre-service inspections should be performed during or at the end of these stages.

#### *Cold performance tests*

4.33. Cold performance testing includes the initial starting of fluid systems and support systems. The objective of this stage is to obtain initial operational data on equipment and on the compatibility of operation with interfacing systems, and to obtain verification of the functional performance of these systems. The tests usually include the pressure test of the primary system and secondary system.

4.34. Where a pressure test required by regulations is not carried out before the transfer of the system to the commissioning group, it should be carried out in this sub-stage as part of the commissioning programme.

#### *Hot performance tests*

4.35. Hot performance tests should be undertaken to verify the conformance of systems with specified requirements. Where possible, these tests should follow cold performance tests, simulating as far as practicable plant operating conditions, including anticipated operational occurrences at typical temperatures, pressures and flow rates.

4.36. The tests should, to the extent possible, verify the effectiveness of heat insulation systems and heat removal systems. They will enable initial checking of flow rates, of vibration, of clearances and of other provisions made for accommodating the thermal expansion of systems and components. The operation of instruments and other equipment at high temperature should be verified and the relevant operating techniques should be confirmed.

4.37. The duration of hot performance testing should be such that a steady state operating condition is achieved, to determine whether the structures, systems and components are operating according to specifications.

4.38. The operating personnel should take the opportunity at this sub-stage to use and to validate operating procedures.

*Initial fuel loading and subcritical tests*

4.39. The purpose of the stage of initial fuel loading and subcritical tests is to ensure that the fuel is loaded into the reactor safely in accordance with the loading pattern calculated in the design. In addition, it should be confirmed at this stage that the reactor is in a suitable condition to be started up, and that all prerequisites for the reactor to have fuel loaded into the vessel and to go critical have been met (see also the Appendix).

4.40. With the core loaded with fuel and the reactor maintained in a subcritical condition, a series of performance tests should be done. These should include checks on coolant flow rates, instrumentation, rod control mechanisms, the automatic system for rod insertion and any other reactivity control systems, and other important features of the primary circuit.

4.41. The plant should be prepared well in advance for the initial fuel loading. The prerequisites regarding testing, systems, equipment, documentation and personnel should be established (see Appendix). These prerequisites, including satisfactory performance of the integrated plant systems and the containment, should be clearly specified and documented on the basis of the safety analysis report and the existing regulatory requirements. These prerequisites should be satisfied well in advance of the commencement of fuel loading.

4.42. The requirements and procedures should be put in place to test the fuel loading machine and any other necessary systems or equipment before the commencement of fuel loading. The personnel responsible for fuel loading should be qualified and trained in advance. Proper training should be carried out on the fuel machine using dummy fuel assemblies, including training in operations in the reactor cavity and the spent fuel pit.

4.43. Fuel should be loaded in accordance with a written procedure to ensure safe and correct loading. Attention should be paid to adequate monitoring of the neutron flux to prevent inadvertent criticality and, if prevention fails, for the timely detection of criticality. An adequate means should be available to restore the subcriticality margin in the event of an approach to inadvertent criticality.

4.44. Initial fuel loading should not be authorized unless all pre-operational tests and pre-service inspections deemed necessary by the regulatory body and the operating organization have been performed and the results obtained are acceptable to both parties.

4.45. Initial fuel loading should be supervised by duly authorized personnel (licensed if necessary). Any unexpected occurrences should be reported immediately to the control room personnel.

4.46. The fuel loading procedure should require, as appropriate: periodic data recording; audible indication of flux increases; and monitoring of neutron count rate instruments when fuel is being inserted and/or when other operations are being performed that could affect core reactivity. In addition, subcriticality checks should be performed at regular steps in the loading procedure to determine the safe loading increments for subsequent loading. Predictions of the behaviour of the core in terms of its reactivity should be available for evaluation of the subcriticality margin. The procedures should require that if actual measurements deviate from the predicted values, further fuel loading be stopped until the

circumstances have been analysed, the reasons for the deviations have been determined and reviewed, and any appropriate corrective action has been taken. (The Appendix provides guidance on the details to be included in the procedures for fuel loading.)

4.47. The exact position for each fuel assembly should be clearly indicated in the loading procedures or the loading plan, and the positions should be documented during the fuel loading operations. By the end of fuel loading, the position of each core element should be independently confirmed and documented.

4.48. In heavy water reactor systems, criticality may be achieved either by the introduction of the moderator, or by the controlled reduction of dissolved neutron absorber in the moderator after initial fuel loading. The precautions for preventing inadvertent criticality during this sub-stage should be specified accordingly. For example, the moderator introduced should have an adequate quantity of dissolved absorbers (such as boron or gadolinium).

4.49. After fuel loading, performance tests should be undertaken to check the characteristics of coolant flow and the effects on components, as well as the mechanical operability of reactor control equipment. During these tests it is required to ensure subcriticality.

### **Initial criticality**

4.50. Before reactivity is increased ('inserted') to approach initial criticality, the necessary prerequisites should be met to ensure that the reactor is in the proper condition for startup, in terms of the availability and readiness of qualified personnel and systems important to safety. It should be adequately documented that these prerequisites have been met and the reactor is in the proper condition for startup, and that the appropriate approvals to proceed to this stage of commissioning have been obtained.

4.51. Before the approach to criticality is started, the startup monitoring instrumentation and the associated automatic shutdown system should be confirmed to be available and operable.

4.52. Measures should be taken to ensure that the startup proceeds in a safe and orderly manner. For this purpose, changes in reactivity should be continuously monitored and evaluated so that the prediction of the point of criticality is continually checked. The sequence and magnitudes of changes in reactivity, made by means of removal of the absorber and/or adjustment of the moderator level, should be specified in the procedures. If un-anticipated changes in reactivity occur at any point in the start-up, then immediately the reactor should be shut down. Operators should not proceed until the reason for the prior unanticipated reactivity change is understood.

4.53. Instruments for neutron monitoring at startup should be calibrated before the approach to criticality and the required minimum neutron count rate should be obtained, using in-core neutron sources if necessary. Trip set points should be reduced to a minimum level compatible with the demands of the tests scheduled in this sub-stage.

4.54. The procedures for achieving criticality after significant subcritical multiplication has been experienced require a cautious approach, through continuous monitoring of the neutron flux and predictions of the point of criticality and successively smaller adjustments in positive reactivity. The objective of these actions is to avoid passing through the point of criticality with a high rate of change in neutron flux (that is, with a short period of multiplication). After

criticality has been achieved, a conservative startup rate of flux increase should be used in attaining low power. The process of achieving criticality should be adequately documented.

#### *Low power testing*

4.55. At the stage of initial criticality and low power tests, the initial criticality of the loaded core is achieved for the first time. The subsequent low power tests should be carried out to confirm that:

- The performance of the reactor core is commensurate with predictions made in the core design;
- The reactor core is in a proper condition for operation at higher power levels;
- The characteristics of the reactor core coolant, reactivity control systems and shielding (as appropriate) and reactor physics parameters are in accordance with predictions made in the core design.

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 and values used in the safety analysis report. The power levels for low power testing should be the lowest power levels that give reliable and stable measurements and that enable the required conditions necessary to perform the specified tests to be achieved. Special startup instrumentation should be provided if necessary.

4.56. Where necessitated by the reactor design, system flow tests and cold and hot tests of appropriate duration should be made with the loaded core. In these tests the trip limits of the nuclear flux channel for the reactor protection system should be set to a conservative level.

#### *Power ascension tests*

4.57. This stage of commissioning consists of a step by step approach to full power and full power tests. At each sub-stage a series of tests will be carried out at specified power levels. Typical steps are 10%, 25%, 50%, 75%, 90% and 100% of full power, or agreed individual steps.

4.58. A comprehensive range of power tests should be made 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. Those tests that are necessary to demonstrate safe operability should be completed without delay. This stage should in general be limited to those tests that can be carried out only at power.

4.59. Tests should be made 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 and load rejections initiated at appropriate power levels.

4.60. A review should be carried out at the end of the stage to confirm whether the operational limits and conditions are adequate [8], and to identify any constraints on the operation of the plant that the commissioning tests have shown to be necessary.

## REVIEW, EVALUATION AND REPORTING OF TEST RESULTS

### **Review and evaluation of test results**

4.61. After the completion of each test, the test results should be reviewed to provide assurance that the test was carried out as intended, that the results demonstrate that the performance of the systems tested is in accordance with the design intent for the plant, and that any operating constraints have been identified. The review process should ensure that all necessary data have been obtained and analysed, and that a technical evaluation and test report have been completed. It should also provide assurance that the succeeding stages can be conducted safely and that the safety of the plant is never dependent on the performance of untested structures, systems or components.

4.62. The evaluation process should ensure that the interpretation of test data is appropriately reviewed by competent persons who have the technical expertise to determine that the operational characteristics of structures, systems and components and/or the testing process is performing satisfactorily. The evaluation of the test results should include a comparison with the acceptance criteria, an evaluation of the availability of design margins and an analysis of any deviations detected.

### **Review of the stage completion**

4.63. At the end of a stage, the results of all the tests in that stage and the general condition of the plant should be reviewed by the representatives of the commissioning group and the operating organization prior to approval being granted to begin the next stage. Depending on the national regulatory practices, the regulatory body may be involved in the review and approval of the results of the specific stage and approval to begin the next stage.

4.64. Reviews should be carried out to ensure that all systems and special testing equipment for the tests in the next stage will be available before proceeding to that stage, and that all relevant administrative and control procedures will be complied with, as documented.

4.65. To ensure that the commissioning programme proceeds in an orderly manner, suitable preparations should be made so that the stage completion and approval documents can be produced in accordance with the schedule. To this end, reviews of test results should be undertaken and test results should be accepted at suitable times during the progress of testing in each stage. The end of each stage should include preparations for the start of the succeeding stage and a means should be arranged for the continual updating of documentation (see Section 5). In addition, close liaison should be maintained with all participants in the commissioning programme, including personnel at the headquarters of the operating organization and personnel of the regulatory body.

4.66. Progress to the next stage should only be permitted by the operating organization when the completed review of the current stage has been approved by the operating organization in accordance, where relevant, with the requirements of the regulatory body.

## **Approvals and issue of test reports**

4.67. Documents should be prepared and issued during the progress of the commissioning activities to document the performance of the tests and to provide stage clearances for the continuation of the commissioning programme. The approval of the regulatory body should be obtained when this is required.

## **Reporting of test results**

4.68. The commissioning group should report the test results to the relevant participants in the commissioning programme. Although it may be convenient to prepare summary reports for a quick assessment of the test results, a formal comprehensive report containing all the required information, including a collation and final evaluation of the test results, should also be prepared. These formal reports should be retained for the purposes of record keeping. In addition to individual tests, stage test reports and a final plant commissioning report should be prepared.

## **HANDLING OF DEVIATIONS DURING COMMISSIONING**

4.69. During commissioning, changes to the plant design, the programmes or the tests may be necessary, unexpected results may be obtained and incidents may occur. The operating organization should establish procedures for dealing with these situations in the framework of its management system.

## **Modifications**

4.70. In making proposals for modifications, account should be taken of: regulatory requirements; the stipulations of the operating organization; the effects of the proposed modification on any other system; and the safety implications of the proposed modification for the commissioning programme or the individual test.

4.71. Where safety is a factor, modifications to plant systems and components should be made as recommended in Ref. [2]. The procedures for making modifications should cover design, safety reassessment and methods of implementation and testing. The scope of the assessment should correspond to the safety significance of the proposed modification.

4.72. 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 performed in accordance with the management system of the operating organization.

4.73. If there is a need to change the sequence of the tests, an appropriate review should be performed prior to varying this sequence from the intended programme. The review should ensure that all the prerequisites for the out of sequence test are met to ensure the safe performance of the test.

4.74. Unavoidable temporary modifications that interfere with the intended design configuration should be properly controlled. An appropriate review should be performed to ensure that safety implications are properly considered.



4.75. Additional guidance on arrangements in connection with anticipated plant modifications during the commissioning stage is provided in Ref. [2].

### **Unexpected test results and occurrences**

4.76. In spite of adherence to appropriate design, construction, commissioning procedures and work methods, unexpected test results or occurrences may arise during commissioning. To ensure that adequate consideration is given to such events, the following procedure should be adopted:

- (1) Commissioning documents should be compiled, containing, where appropriate, instructions for the immediate actions to be taken if the results obtained in the course of the test fall outside the specified limits or if unexpected events occur.
- (2) A review should be carried out to explain the cause(s) of the event and to decide on the corrective actions and preventive actions to be taken.

## **5. DOCUMENTATION ON COMMISSIONING**

### **ARRANGEMENTS FOR COMMISSIONING DOCUMENTATION**

5.1. The commissioning documentation is important for the subsequent safe operation of the plant. The structure, content, extent and control of commissioning documents should therefore be specified in the management system of the operating organization.

5.2. Arrangements for documentation for commissioning should provide the following:

- Continuity in the commissioning activity and a means for the continual updating of documents to facilitate the execution of stage reviews;
- Evidence to the various participants that the design intent has been met or that deviations if any have been assessed and that appropriate modifications have been made;
- Assurance to the operating organization that commissioning is proceeding safely;
- Records that need to be kept available throughout the lifetime of the plant;
- Assurance to the regulatory body that its requirements are being met.

5.3. The preparation, review, approval and control of commissioning documentation should be in accordance with the management system [9]. All commissioning documentation, including latest approved issues, completed test documents and test reports, should be retained in an appropriate location for both control and archival purposes.

5.4. Methods for the preparation, safe keeping, retrieval and review of documents should be specified. Document control procedures should be put in place to ensure that those persons participating in a commissioning activity are provided with approved procedures.

## SCOPE AND STRUCTURE OF COMMISSIONING DOCUMENTATION

5.5. The commissioning documentation should comprise the organization and management documents for commissioning, the commissioning procedures and the reporting documentation for commissioning.

### **Management system manual for commissioning**

5.6. The management system manual for commissioning (commissioning manual), or a similar document regulating the commissioning process, should form part of the suite of commissioning documentation that sets out the management organization and the documentation processes. The commissioning manual should detail the management structure for commissioning to enable commissioning activities to be logically planned and safely executed.

5.7. The purpose of the commissioning manual is to specify the organizational structure and responsibilities for the management and control of testing and commissioning, to meet the requirements for quality, established requirements, statutory obligations and the licence provisions. The commissioning manual should specify the extent and nature of and the approval process for the documentation, including procedures and certificates to be used during commissioning.

5.8. The commissioning management system manual should provide the basis for the planning and execution of the testing and proving of plant structures, systems and components and plant items, as a coordinated activity in the operating organization and between the operating organization and its relevant contractors.

5.9. The commissioning manual, referring as appropriate to the management system, should include the following items of the commissioning process:

- The objectives of commissioning;
- The management policy of the operating organization;
- The responsibilities of the participating organizations with regard to the commissioning of the plant;
- The organizational structure for commissioning;
- The management for commissioning;
- The commissioning programme;
- Safety aspects;
- The change management process for deviations detected during commissioning;
- Arrangements for the documentation for commissioning.

### **Administrative procedures**

5.10. Procedures should be established by the organization responsible for the control of commissioning activities at the site to ensure that the commissioning of the plant fulfils the provisions of the commissioning programme. These controls will usually be in the form of administrative procedures, which will include all administrative controls and requirements for carrying out commissioning activities. Arrangements should be made in the framework of the

management system to ensure that these procedures are reviewed and approved before issue, and that their subsequent amendment is controlled.

### **Commissioning programmes and procedures**

5.11. The commissioning documentation should include basic information on the principles and objectives of the plant commissioning tests as well as details of the testing to be carried out on the plant. Such documentation should contain sufficient information about the design, function and expected performance of the plant systems to characterize adequately the system for subsequent specification of proposed tests. This documentation may also include the vendor specifications, design basis and safety analysis report and records of subsequent changes to any of these documents, the requirements of the regulatory body, licences and other relevant statutory documents. Such information should also substantiate the proposed commissioning tests and should clearly address any specific precautions or measures for protection and safety required during the tests. The substantiations of testing may be presented as a separate document or may be included in the testing procedures.

### **Programmes and schedules**

5.12. The overall plant commissioning programme is a document giving a general presentation of the programme (process) of commissioning a particular nuclear power plant or a nuclear power unit as a whole, a description of the different commissioning stages and associated commissioning activities, and the overall schedule of the commissioning stages for the plant.

5.13. System commissioning programmes are related to a system (or a group of systems, or other particular scope of commissioning). Each system commissioning programme gives a brief description of the objectives, principles, test conditions and acceptance criteria for all the tests to be performed in the test stages for the system(s) concerned, including references to the documents to be used for the performance of tests (test guidelines, test procedures), the stages during which they are performed and their logical sequence.

5.14. Stage commissioning programmes are related to a single stage (or sub-stage) of commissioning. The stage commissioning programme specifies the prior conditions for starting the stage, as well as any waivers with respect to the technical specifications (and more generally operating limits and conditions) after fuel loading. It gives the chronology of all the tests and activities to be carried out during the stage. It also includes the list of test procedures to be performed during the stage, and the list of operating procedures and periodic testing procedures to be applied and/or validated during the stage.

### **Test procedures**

5.15. All commissioning activities should be performed in accordance with approved written procedures. The preparation of test procedures, including their verification and approval, should be specified in the management system of the operating organization. The level of review should reflect the importance to safety of the plant component and/or system and the nature of the test. The procedures that are established should provide for timely reporting to allow commissioning to proceed safely and efficiently.

5.16. The test procedures should be subject to a thorough verification that involves the operating organization. The designers and the regulatory body, if necessary, should also participate in the approval process, and in particular in reviewing the validity of the acceptance criteria.

5.17. On the basis of the tests scheduled in the commissioning programme, testing procedures should be prepared for each of the individual plant item tests and system tests. Each procedure should detail the objectives of the testing and should contain detailed instructions for the members of the test team carrying out the work. In addition to detailed step by step instructions, the procedures should contain specific information about safety requirements, emergency procedures, collection of test data and acceptance criteria for the test data.

5.18. Although the format of procedures may vary from plant to plant, the contents of test procedures should include, but are not limited to, the following topics specified in paras 5.19-5.32.

#### *Introduction*

5.19. A summary should be given of the main objectives of the test and of the aspects of safety to be demonstrated. The system to be tested should be identified and the anticipated results of the test should be indicated. The relationship of the test being carried out to the main stages of the commissioning programme should be highlighted.

#### *Test objectives and methods*

5.20. The detailed objectives of the test and the methods by which they are to be achieved should be stated.

#### *Operational limits and conditions*

5.21. Applicable operational limits and conditions, including appropriate temporary operational limits and conditions, should be stated. In addition, those plant limits and conditions that must be observed to prevent damage to the plant should also be included.

#### *Prerequisites and initial conditions*

5.22. The state of all relevant systems and components and other pertinent conditions that might affect the operation of the system to be tested should be stated, particularly if different from normal. This information should include, where appropriate, the precautions necessary to maintain the desired system configuration.

#### *Test conditions and procedures*

5.23. The way in which the system to be tested is required to be brought up to test conditions should be specified. Details of the test procedures should be provided, preferably in a step-by-step format, including data to be collected together with the expected values. This should

include any temporary changes or abnormal alignments of the system or the adjacent systems, including those reported by construction groups.

#### *Acceptance criteria*

5.24. The acceptance criteria, especially safety related criteria, should be stated and this statement should wherever possible be quantitative as well as qualitative (for fuel loading, for example). The origin of the criteria should be mentioned.

#### *List of instrumentation and special test equipment*

5.25. Any special equipment and calibrations necessary to perform the test should be specified. Attention should be paid to ensuring that such equipment is clearly identifiable and of appropriate accuracy.

#### *Staffing, qualification and responsibilities*

5.26. Staffing needs, qualification requirements and assignment of duties and responsibilities for conducting tests should be specified as necessary.

#### *Special precautions/contingency plan*

5.27. Special precautions necessary for protection and safety should be clearly described in the test procedure. In addition, any special precautions necessary to ensure protection and safety should be stated and a contingency plan, if required, prepared on the basis of a hazard analysis should be put in place.

#### *Completion of test*

5.28. Provision should be made for a statement by the individuals responsible to indicate that the test has been completed (irrespective of whether the results are satisfactory or not) and that the systems have been returned to normal conditions or the anticipated conditions at the end of the test. The removal of temporary changes or of any abnormal line-up should be individually specified; for example, as steps in the test procedure.

#### *Permanent records*

5.29. A list of information necessary for permanent records should be provided, including baseline data to be collected in the test.

### *Identification, cross-referencing and distribution*

5.30. Each authorized test procedure should incorporate a unique identification (such as by reference numbering), including comprehensive cross-references to associated documents and a distribution list of those persons who should receive it.

### *Data collection and processing*

5.31. The test procedures should include arrangements for tabulating data and test results. Test sheets should have standardized forms and each sheet should be signed by the collector of the data. Chronological recording is desirable (test data, date and time). Data preprocessing by the data acquisition system and post-processing, if any, should be validated and verified.

### *Non-conformity management*

5.32. The test procedure should describe the procedure or refer to the relevant process of the management system for managing the non-conformities identified as results of the test.

## **Records**

### *Test reports*

5.33. A report should be drawn up on the results of all tests included in the testing programme. Formal reports for each test should be prepared and approved in accordance with the processes under the management system. The format of a report may vary but typically it should include:

- (a) Introduction;
- (b) References to appropriate test procedures;
- (c) Description of the method of testing and summary of the objectives for each test;
- (d) The conduct of the test, including the initial and final states of the plant, the actual limitations experienced, and problems encountered and the actions taken to overcome them, including any modifications to the plant or to the procedures;
- (e) Concise description of any special test equipment used;
- (f) Detailed datasheets with expected values and plots of test data obtained;
- (g) Summary of data collected and analyses of the data;
- (h) Evaluation of results, including statements that the acceptance criteria have (or have not) been met;
- (i) Conclusions;
- (j) Identification, cross-references to associated documents and a distribution list of those persons who should receive the report.

### *Stage reports*

5.34. A summary report should be drawn up on each stage (or sub-stage) of the testing. The stage report should contain essential results of the test stage concerned. The report should

contain a summary of the observations made during the testing, as well as an assessment of the appropriateness of the testing performed (and of the results achieved) in the stage concerned and a summary of any necessary changes to the testing programme or to the plant.

#### *Records of deficiencies and reservations during commissioning*

5.35. The commissioning documentation should also include the reports on defects that should be created and updated throughout the commissioning phase. All reservations about tests that have not been fully carried out and/or closed out at the time of endorsement of the test report should be presented in these reports.

#### *Certificates*

5.36. Documents should be prepared and issued during the progress of the commissioning activities to report on the performance of the tests and to provide the required inputs for the continuation of the programme, in accordance with the procedures established by the operating organization. Different types of documents may be used to certify the completion of the test or the group of the tests in a commissioning stage.

5.37. A test certificate can be issued to certify that the test has been completed in accordance with the established procedures. A stage completion certificate can be issued to certify that all the tests in the commissioning stage have been satisfactorily completed. It should also list associated test certificates.

#### *Plant and system handover documents*

5.38. Documents should be prepared and issued for the handover of plant systems to certify formally that the plant system was installed and tested as required under the commissioning programme and that the system is functioning in accordance with the design intent and provisions. The handover certificate should be supplemented by the handover acceptance package.

5.39. The transfer of documentation is a key feature in the handover process. Documentation should be transferred in system packages and over a reasonable period of time for the plant personnel to be able to make a comprehensive review of every package. These transfers should also depend on how the responsibilities are assigned for the testing after fuel loading, at initial criticality, at low power and at power ascension.

#### *Supporting documentation*

5.40. The documentation on commissioning should include supporting information presented in the form of guides or procedures that are needed to support the activities in the commissioning process. Examples of such documents are records relating to the locations of fuel assemblies and other nuclear materials, procedures for radiation protection and safety, and associated records. Where relevant, all supporting information on tests that is not included in the test procedure as well as any documentation used to evaluate and judge the performance of the test should be referenced in the appropriate section of the test report.

## **Appendix 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. The list should apply in detail in all commissioning stages.

### **PREREQUISITES FOR FUEL LOADING**

A.2. The following activities and checks should be considered for completion before fuel loading:

- Verification of the configuration of all relevant systems as specified in the design documentation;
- Inspections of fuel assemblies, reactivity control devices and other neutron absorbers, and the identification of 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);
- 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 as well as the response of the instrumentation to a neutron source;
- Status of the containment and of the primary circuit as specified, with components correctly placed or removed as specified;
- Status of the coolant and coolant circulation, 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 lockouts;
- Operability of appropriate reactivity controls and readiness for reactor shutdown by the 'insertion' of negative reactivity;
- Conformity of the reactivity condition of the reactor core with specifications, and ensuring the shutdown margin by making conservative assumptions about conditions and by locking off power supplies to prevent the inadvertent 'removal' (reduction) of negative reactivity;
- Operability of fuel handling equipment, including on-site trials of fuel handling equipment using dummy fuel assemblies;
- Availability of a detection system for failed fuel;
- Capability to unload failed fuel and store it separately in a pre-specified place;
- Status of protection systems, interlocks, mode switches, alarms and radiation protection equipment as specified;
- High flux trip points set for a relatively low power level (approximately 1% of full power) for operability of control rods during fuel loading, and alarm and trip settings of other protection channels set to low values;
- Availability of criticality precautions;
- Capability of shutting down the reactor from the emergency control room; Status of emergency core cooling system;
- Availability of post-accident sampling system;



- Availability of post-accident radiation monitoring system;
- Control and segregation of any moderating materials;
- Status of cleanness at the plant;
- Composition of the fuel handling crew, and their duties and responsibilities in the event of an emergency;
- Operability of radiation monitors, nuclear instrumentation, and manual and automatic devices for actuating building evacuation alarms and ventilation controls;
- Approval of fuel loading by the regulatory body.

## TEST CONDITIONS AND PROCEDURES

A.3. The following items should be considered for inclusion in the conditions and procedures for the fuel loading test:

- Fuel handling, including the precautions to prevent criticality and physical damage;
- Loading sequences and patterns for the different types of fuel (in terms of grades of enrichment and ‘poison’ elements), control rods, and other neutron absorbers and components;
- Guidance on fuel addition increments with fuel loading arranged so that the reactivity worth of the individual fuel elements inserted decreases as the core is assembled;
- Provisions to measure radiation doses to personnel during initial fuel loading;
- 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;
- Information on proper positioning and orientation of fuel and components, and checking of fuel identification;
- A functional test of the associated control rod (for boiling water reactors) as the installation of each fuel cell is completed;
- Requirements for nuclear instrumentation and neutron sources for monitoring subcritical multiplication, including methods for relocation of sources or detectors and normalization of count rate after relocation (a minimum of source range monitors should be required to be operable whenever operations are performed that could affect the reactivity of the core);
- Flux monitoring information, including counting times and frequencies, and rules, as necessary, for plotting a curve for inverse multiplication and interpreting plots using at least two channels;
- Limits on fuel loading increments, if applicable, on the basis of an extrapolation and conservative interpretation of these plots (see the item on flux monitoring information above), and other predetermined limits on loading increments as specified in advance;
- Expected subcritical multiplication behaviour;
- In case control rods are completely inside the core (as for pressurized heavy water reactors), the secondary shutdown system with an appropriate trip set point for actuation to be poised during initial fuel loading;

- Confirmation of the minimum shutdown margin and performance of tests of rod reactivity worth in unborated reactors, and the frequency of confirmation during loading and on completion (for borated reactors, this necessitates the 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);
- Actions for periods when fuel loading is interrupted, especially those pertaining to flux monitoring;
- Establishment of measures for radiation protection;
- A method of maintaining adequate communication between the control room and the loading station;
- The minimum number of personnel necessary to load fuel;
- Specification of the permitted working time of the personnel;
- Establishment of criteria for stopping fuel loading, such as unexpected subcritical multiplication behaviour, loss of communication between the control room and the fuel loading machine, inoperability of a source range monitor or inoperability of the emergency shutdown system;
- Specified limits of the counting period for count rates;
- Establishment of criteria for reducing the fuel loading increment, if applicable (if this increment is reduced because of excessive subcritical multiplication, it is not to be increased again);
- Establishment of criteria for emergency injection of fuel poison (or tripping of the shutdown control rod groups);
- Specified limits for the quality of the reactor coolant;
- Establishment of criteria for containment evacuation;
- Actions to be taken in the event of fuel damage;
- If any stated limits have been reached or exceeded, actions to be taken or approvals to be obtained before routine loading may resume.

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## **Annex**

### **LISTING OF TYPICAL COMMISSIONING TESTS**

#### **INTRODUCTION**

A-1. This Annex provides a listing of typical tests to be considered in the development of a commissioning programme. These lists of tests are neither complete nor applicable to all reactor types. These lists of tests are mainly based on water reactor technology; they are illustrative only and certainly not exhaustive. Reactors are now being designed which include many passive safety features or which do not include some parts of the systems mentioned here. Clearly the commissioning for such reactors will differ in many respects.

#### **PREREQUISITES FOR PRE-OPERATIONAL TESTS**

##### **Functional tests of individual subsystems or components**

A-2. Typical tests to be considered are the following:

- (a) Valves: 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.
- (b) Motors and generators: direction of rotation, vibration, overload and short circuit protection, margins between set points and full load running current, 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).
- (c) Pumps, fans or gas circulators: vibration, motor load versus time, seal or gland leakage, seal cooling, flow and pressure characteristics, lubrication, acceleration and coast-down, automatic start-up after power disruption.
- (d) Piping and vessels: pressure tests; leak-tightness, cleaning and flushing; clearance of obstructions; support adjustments; proper gasketing; bolt torque; insulation; filling and venting.
- (e) Instrumentation and control: voltage, frequency, current, circuit breaker operation, bus-bar transfers, trip settings, operation of prohibiting and permissive interlocks, calibration, probe sensing lines.

#### **PRE-OPERATIONAL TESTS**

##### **Reactor coolant system**

A-3. The reactor coolant system includes all pressurized components such as pressure vessels, pressure tubes, piping, ducting, pump and circulator casings 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.

- (a) System tests: expansion and restraint tests to confirm acceptability of clearances and displacements of vessels, piping, ducting, piping hangers, hold-down support, or

restraining devices such as for seismic protection in the as-built system; hot performance and/or cold testing of the system with simultaneous operation of auxiliary systems, including chemical control aspects.

- (b) Component tests: appropriate tests and measurements of reactor coolant system components, including:
  - Pressurizer;
  - Pumps, fans or gas circulators with associated motors;
  - Steam generators;
  - Pressure relief valves (and associated dump tanks and cooling circuits, if any) and supports and restraints for discharge piping;
  - Safety valves;
  - Other valves;
  - Instrumentation used for monitoring system performance or performing prohibiting and permissive interlock functions;
  - Reactor vessel and internals, including checks of pre-stressed concrete tendons;
  - Jet pumps or internal recirculation pumps;
  - Reactor gas plant.
- (c) Vibration tests: vibration monitoring of reactor internals and other components such as piping systems, heat exchangers, steam generator tubing and rotating machinery.
- (d) Pressure boundary integrity tests: baseline data for subsequent in-service testing.

### **Moderator system**

A-4. Tests on the moderator system include:

- (a) System tests: cold performance test of the moderator channel system, including cover gas system and auxiliary systems for chemical control, and moderator and/or fuel channel alignment checks.
- (b) Component tests: appropriate tests of system components, including:
  - Cover gas pressurizer;
  - Pumps, compressors and motors;
  - Gas recombination units;
  - Pressure relief devices;
  - Devices for injection of chemical absorbers.

### **Reactivity control systems**

A-5. Tests on the reactivity control systems include:

- (a) Tests of the chemical control system: proper blending of boric acid solution and moderator, uniform mixing and adequacy of sampling and analytical techniques, operation of heaters and trace heating; operation of instrumentation, controls,

interlocks, 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.

- (b) Tests of the liquid poison system: operation of the system with demineralized water; mixing of moderator solution and adequacy of the sampling system; operability of instrumentation, controls, interlocks and alarms; operability of trace heating; operation of quick acting valves including test firings of squib actuated valves; redundancy and electrical independence.
- (c) Tests of the control system and shutoff system: normal operation and shutdown capability including cooling requirements; scram times and, where applicable, friction tests; appropriate performance of inhibiting and other functions in the system logic (such as rod selection, insertion, withdrawal and runback features, sequence control devices and rod worth minimizers); instrumentation for rod position and interaction of the control and shutoff drive systems with other systems such as automatic reactor power control systems and refuelling equipment; correctness of failure mode on loss of power for the rod drive systems; and appropriate operation of system alarms.

### **Reactor protection systems**

A-6. Tests 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 logic, 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 any 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 converter protection).

### **Power conversion system**

A-7. The power conversion system includes all 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 tests and other appropriate tests are to be carried out on the following systems and components:

- Steam generators;
- Steam and feed-water process lines;
- Auxiliary coolant systems;
- Relief and safety valves for steam generator pressure;
- Emergency feed-water pump;
- Stop, control, intercept and bypass valves for the turbine;
- Feed-water system;
- Condenser circulating water system;

- Make-up water and chemical treatment systems;
- Steam extraction system;
- Control system for the hot well level of the main condenser;
- Feed-water heaters and drainage systems;
- Main condenser auxiliaries used for maintaining condenser vacuum;
- Condenser off-gas system.

### **Auxiliary and miscellaneous systems**

A-8. Appropriate tests are 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 system whose performance is demonstrated by testing:

- Reactor coolant make-up system: capability during all operational states and accident conditions;
- Seal fluid system;
- System for seal and pump cooling fluid;
- Vent and drainage systems;
- Fire protection systems, including manual and automatic operation of fire detection, alarm and suppression systems;
- Service water and raw water systems;
- 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;
- Compressed gas systems, including the instrument air system and other compressed gas systems used for safety related functions;
- Emergency condenser system, residual heat removal system and system for post-trip shutdown logic;
- Cooling system for reactor core isolation;
- Cooling system for reactor vessel head;
- Shield cooling system;
- Leak detection system: sensitivity and accuracy to detect leakage of primary fluid through the boundaries of the reactor coolant system, the moderator system, and the auxiliary system or the emergency cooling system, or to detect leakage of secondary coolant into the primary coolant;
- Primary pressure relief system;
- Boron recovery system;
- Communication systems: operation of evacuation and other alarms, public address system in 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;
- Chemistry control systems for the reactor coolant system and secondary coolant systems;
- Cooling and heating systems associated with spent fuel storage if necessary;
- Equipment and controls for establishing and maintaining subatmospheric pressure in subatmospheric containments;
- Component cooling water systems;



- Reactor coolant and secondary sampling systems;
- Closed loop cooling water systems;
- Purification and cleanup systems.

## Electrical systems

A-9. The plant electrical systems include the normal AC power distribution system, the emergency AC power distribution system, the emergency AC power supplies, and the DC supply and distribution system.

- (a) 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, capability to transfer from on-site to off-site power sources.
- (b) Vital bus-bar and associated AC power supplies: load tests that use all and minimum sources of power supplies to bus-bars.
- (c) 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 undervoltage alarms and ground detection instrumentation; redundancy, electrical independence and actual total system loads, a discharge test of each battery bank at full load and for the design duration of load, adequacy of emergency lighting.
- (d) Emergency AC power distribution system: operation of protection devices, relaying 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 source 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; (to the extent practicable) testing of emergency or vital loads conducted for a sufficient period of time to provide assurance that equilibrium conditions are attained; verification of system redundancy and electrical independence; testing of loads supplied from the system such as motor generator sets with flywheels designed to provide non-interruptible 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.
- (e) Emergency or standby AC power supplies: redundancy, electrical independence, and proper voltage and frequency regulation under transient, steady state and emergency conditions; performance of auxiliary systems such as those used for starting, cooling, heating, ventilating, lubricating and fuelling, duration of test to ensure that equilibrium conditions are attained; logic, correctness of set points for trip devices and proper operation of initiating devices, prohibiting and permissive interlocks, redundancy and electrical independence.

## **Containment systems**

A-10. In tests on the primary and secondary containment systems, account is to 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 is to be paid to:

- Integrated and partial (penetration air lock and valve) leakage testing of containment, and overpressure (or vacuum) structural test;
- Functional tests on isolation valves and on initiation logic;
- Containment vacuum breaker testing;
- Functional testing of auxiliary containment systems such as the purge system and systems for air purification, gas treatment and inerting;
- Primary and secondary ventilation system tests; leak collection and exhaust system tests; dousing or spray water system tests.

## **Systems for management of radioactive waste**

A-11. Tests on radioactive waste management systems include those designed to demonstrate the operability and to 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, holdup times and proper operation and calibration of associated instrumentation.

## **Fuel storage and handling systems**

A-12. Tests on fuel storage and handling systems are to demonstrate operability in accordance with the design intent of equipment and components used to handle or cool irradiated fuel and to handle non-irradiated fuel. These may include:

- Integrity testing or inspection of spent fuel storage and its liner;
- 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);
- Tests on refuelling equipment and fuel lifting devices (including hand tools, power equipment, bridge and overhead cranes and grapples) and operability of protective interlocks and devices;
- Tests on containment devices, and for leakage and ventilation in the fuel discharge route;
- Tests on fuelling machines, control and hydraulic systems, and pressurizing and cooling equipment;
- Appropriate tests or inspections of storage facilities for ensuring subcriticality;
- Handling test on fuel transfer flasks.

## **Handling systems for reactor components**

A-13. Tests on the handling systems for reactor components cover equipment handling, hoists used for reactor components that need to be moved (for example, for refuelling or for reactor vessel inspection), and protective interlocks on cranes and hoists.

## **Radiation protection systems**

A-14. Appropriate tests on systems and components used to monitor or measure radiation levels to provide for radiation protection of personnel or to control or limit the release of radioactive material include the following:

- Process tests, effluent tests and area radiation monitor tests;
- Tests on personnel monitors and radiation survey instruments;
- Tests on laboratory equipment used to analyse or measure radiation levels and activity concentrations;
- In situ efficiency tests of high efficiency air filters, adsorption filters and delay beds.

## **Instrumentation and control systems**

A-15. 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 actions and to monitor events. Instrumentation and control systems have to be tested over the design operating range, and limiting malfunctions and failures have to 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 converter protection).

A-16. A listing of instrumentation parameters and items for testing (some of these items may be tested in conjunction with the control system) typically includes the following:

- Pressurizer pressure and level;
- Reactor vessel level;
- Reactor coolant flow;
- Feed-water control;
- Automatic control of reactor temperature and power;
- Steam pressure in the secondary system;
- Detectors for leaks in the reactor coolant system;
- Reactor and primary circuit diagnostic systems;
- Instrumentation initiating the emergency core cooling system and containment spray;
- Annunciators for reactor control and engineered safety features;
- Equipment to measure chemical parameters;
- Reactor start up instrumentation;
- Instrumentation and controls used for achieving and maintaining safe shutdown from outside the control room;
- In-core and ex-core neutron instrumentation;
- Detection of failed fuel;
- Traversing in-core probes;
- Monitoring of loose parts;
- Pressure control to maintain design differential pressures;
- Seismic instrumentation;
- Detectors monitoring for external and internal flooding conditions;
- Instrumentation monitoring the course of postulated accident conditions;
- Post-accident hydrogen monitors and analysers used in the control system for combustible gas;

- Computer control, monitoring and logging systems.

### **Engineered safety features**

A-17. 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 engineered safety features commonly provided:

- 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;
- Auto-depressurization system;
- Systems for post-accident removal of heat from the containment, spray systems and recirculation fans;
- Control system for combustible gases in the containment;
- Cold water injection interlocks;
- Emergency water supply system;
- Emergency feed-water system.

A-18. 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 also has to be conducted using the minimum number of operable components available with which these systems are designed to function. These include systems and components such as systems for heating, ventilation and air conditioning, cooling water and seal injection systems and protected compressed gas supplies; protective devices, such as leaktight covers or housings provided to protect engineered safety features from flooding, or devices used to prevent 'water hammer' effects and possible damage to fluid systems.

## **FUEL LOADING, INITIAL CRITICALITY AND LOW POWER TESTS**

### **Tests during fuel loading and initial criticality period**

A-19. Before reactivity is increased ('inserted') to approach initial criticality, the prerequisites for fuel loading (see paras 4.39–4.49 and the Appendix for details), open vessel tests and final checks are to be completed to ensure that the reactor is in proper condition for startup. The following list is illustrative of the types of tests and verifications that are conducted during or after initial fuel loading:

- Tests of withdrawal and insertion speeds for reactivity control rods, sequences, rod position indication, protective interlocks and circuitry, and scram timing of reactivity control and shutoff devices after the core is fully loaded; to the extent practicable, testing has to demonstrate scram times for reactivity control rods at the extreme temperatures and flow ranges for the reactor coolant system;
- Local criticality tests;

- Testing of the reactor protection system: trip point, logic and operability of scram breakers and valves, and manual scram functions;
- Rod drop time measurements: each rod, cold and hot, at rated recirculation flow and with no recirculation flow plus additional measurements for each of the fastest and slowest rods;
- Testing of leak rates for the reactor coolant system;
- Testing of moderator cooling;
- Chemical tests: water quality and boron concentration of the reactor coolant and/or the moderator system;
- 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;
- Monitoring with mechanical and electrical in-core equipment, including traversing in-core probes, if installed;
- Flow tests for the reactor coolant system: verification of vibration levels, of differential pressures across the fully loaded core and across major components in the reactor coolant system; verification of the reactions of 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;
- Test of the effectiveness of the pressurizer (hot shutdown);
- Vibration checks or monitoring;
- Shutdown margin verification for partially and fully loaded core.

### **Low power tests**

A-20. After achieving initial criticality, tests are performed as necessary to verify that the behaviour and characteristics of the core, the 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:

- Particulate and tritium activity monitoring (for pressurized heavy water reactors);
- Neutron and gamma radiation surveys;
- Determination that there is an 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;
- Radiation monitors: verification of their proper response to a known source;
- Measurement of temperature reactivity coefficient for poison and moderator and/or coolant over the temperature range and poison concentration range in which the reactor may become critical;
- Determination of reactivity worth for control rods and the control rod bank, including verification of rod insertion limits to ensure an adequate shutdown

- margin, consistent with the assumptions for accidents (for example, with the control rod of greatest reactivity worth failing to enter the core);
- Measurements of absorber reactivity worth;
  - Determination of absorber concentration at initial allocation of criticality and reactivity;
  - Flux distribution measurement with normal rod patterns (this may be performed at a higher power, consistent with sensitivity of in-core flux instrumentation);
  - Chemical and radiochemical measurements to demonstrate the design capability of the chemical control systems and installed analysis and alarm systems to maintain water quality within limits in the moderator, the reactor coolant and secondary coolant systems;
  - Determination of the reactivity worth of the most reactive rod;
  - 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;
  - Chemical tests of control fluid quality;
  - Comparison of actual critical configuration with the predicted configuration;
  - Leak test of reactor coolant system;
  - Confirmation of calibrations of reactivity control devices as predicted for standard rod patterns (for non-standard patterns, the differential and integral reactivity worths are to be determined);
  - Functional test of the cooling system for the reactor vessel head;
  - Capability of the primary containment ventilation system to maintain environmental parameters in the containment and to maintain important components in the containment within design limits, with the reactor coolant system at rated temperature and with the minimum availability of ventilation system components for which the system is designed to operate;
  - Demonstration of the operability of steam driven engineered safety features and steam driven plant auxiliary equipment and power conversion equipment;
  - 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;
  - Operability of the computer system for process control;
  - Test of scram time for control rods and shutdown rods at rated temperature in the reactor coolant system;
  - Operability of pressurizer relief valves and main steam system relief valves at rated temperature;
  - Operability of residual heat removal systems or decay heat removal systems, including atmospheric steam dump valves and turbine bypass valves;
  - Operability of purification, cleanup and off-gas systems for the reactor coolant system;
  - Measurements or checks of reactor vessel internals and of the vibration of components of reactor coolant systems.

## POWER TESTS

A-21. The following list is illustrative of the types of performance demonstrations, measurements and tests in the power tests stage:

- Natural circulation tests of the reactor coolant system;
- Tests of power reactivity coefficients or power versus flow characteristics;
- Tests of dynamic plant response to the design load swings, including step and ramp changes, and response to automatic control;
- Chemical analyses (at frequent intervals);
- Functioning of chemical and radiochemical control systems and sampling to verify that characteristics of the reactor coolant system and secondary coolant system are within specified limits;
- Effluent monitoring systems: verification of calibration by laboratory analysis of samples (as early in power ascension as possible and repeated at specified power steps);
- Process radiation monitoring systems and effluent radiation monitoring systems: correctness of response;
- 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 to flow conditions;
- Turbine trip tests;
- Tests of trip of generator main breaker: 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 operations;
- Tests with loss of off-site power (over 10% of generator power output);
- Radiation surveys and mapping to determine the effectiveness of shielding;
- On-power refuelling tests;
- Tests of dropped rod: effectiveness of instrumentation in detecting a dropped rod and verification of associated automatic actions;
- Evaluation of flux asymmetry with single rod assembly fully inserted and partially inserted below the control bank, and evaluation of its effects;
- Vibration monitoring of reactor internals in steady state and transient operation, if this testing has not been completed previously;
- Determination of the reactivity worth of the most effective rod;
- Tests of the 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;
- Verification of scram times after plant transients that result in scrams;
- Functional tests of relief valves; verification of operability, response times, set points and reset pressures, as appropriate, for pressurizer relief valves, main steam line relief valves and atmospheric steam dump valves;

- Verification of operability and response times of isolation valves for the main steam line and branch steam line;
- Evaluation of performance of shutdown cooling system; capability of all systems and components provided to remove residual heat or decay heat from the reactor coolant system, including condenser steam dump valves or atmospheric steam dump valves, the residual heat removal system in steam condensing mode and the reactor core isolation 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 startup and operation (before exceeding 25% power);
- Measurement of power control by flow variation and demonstration of flow control;
- Calibration and tests of the pressure regulator, including response to operation of a bypass valve;
- Emergency condenser performance (after shutdown from over 25% power);
- Performance of reactor core isolation cooling system (after shutdown from over 25% power);
- Calibration of reactivity control devices, as necessary, and verification of performance of major or principal plant control systems such as the average temperature controller, automatic reactor control systems, integrated control system; pressurizer control system, reactor coolant flow control system, and main, auxiliary and emergency feed-water control systems; hot well level control systems; steam pressure control systems; and reactor coolant make-up and letdown control systems;
- Rod pattern exchange demonstration (at the maximum power that rod exchange will be permitted during operation);
- Dynamic response of the plant and subsequent steady state of the plant for single and credible multiple trips of the reactor coolant pump or the circulator and/or failure of flow control valves of the reactor coolant system;
- Trip-out of feed-water pump and restart of standby pump;
- Operation of control rod sequencers, reactivity worth minimizers for control rods, rod withdrawal block functions, rod runback, partial scram, operability of the ‘select rod insert’ features;
- Operation of reactivity control systems, including functioning of control and shutdown rods and poison addition systems;
- Operation of the reactor coolant system with the plant in steady state conditions to establish flow rates, reverse flows through idle loops or jet pumps, core and channel flow, differential pressures across the core and major components in the reactor coolant system, and vibration levels of other components;
- Determination of baseline data for the monitoring system for loose parts of the reactor coolant system;
- Determination of effectiveness of leak detection systems for reactor coolant, if not previously demonstrated;
- Operation of failed fuel detection systems in accordance with predictions;
- Operation of shielding and penetration cooling systems: maintenance of temperatures of cooled components with the minimum design capability of cooling available;



- Performance of the auxiliary systems for the operation of engineered safety features with the minimum design capability of operable components in these auxiliary systems;
- Operation of processing, storage and release systems for gaseous and liquid radioactive waste;
- Test of the dynamic response of the plant for a simulated condition of loss of turbine generator coincident with loss of off-site power;
- 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; that is, a direct electrical signal, not a secondary effect such as turbine over-speed);
- Test of the dynamic response of the plant for the case of automatic closure of all main steam line isolation valves (for pressurized water reactors the test may be made at a lower power level to demonstrate proper plant response to this transient);
- Observations and measurements, as appropriate, to ensure that movements, vibrations and expansions of piping and component are acceptable for safety systems (tests performed in low power testing need not be repeated);
- Test of the dynamic response of the core and plant to fast load changes initiated by the load control;
- Test of the capability of plant systems to control oscillations in xenon levels in the core;
- Performance of ventilation systems and air conditioning systems;
- 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 results in the most severe case of reduction in feed-water temperature;
- Tests of the load carrying capabilities of systems, components and cables;
- Tests of shutdown from outside the control room.

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