IAEA SAFETY STANDARDS SERIES

Commissioning for Nuclear Power Plants

SAFETY GUIDE

No. NS-G-2.9

INTERNATIONAL
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IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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COMMISSIONING FOR NUCLEAR POWER PLANTS

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

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FOREWORD

by Mohamed ElBaradei
Director General

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

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

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

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

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

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

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

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

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

EDITORIAL NOTE

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

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

The English version of the text is the authoritative version.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide was prepared under the IAEA programme for safety standards for nuclear power plants. It supplements and elaborates on Section 5 of Safety of Nuclear Power Plants: Operation [1] on safety requirements for the commissioning of nuclear power plants. This Safety Guide is a revision of the IAEA Safety Guide on Commissioning Procedures for Nuclear Power Plants which was issued in 1980 as Safety Series No. 50-SG-O4.

1.2. The revision of the Safety Series publication No. 50-SG-O4 was conducted in accordance with the following:

(a) The technical content of the original Safety Guide was kept in its entirety and updated where necessary.
(b) Additional material resulting from recent experience in the area of commissioning was included.
(c) The text was restructured to be in accordance with the logic of the approach followed in commissioning a nuclear power plant.
(d) The Safety Guide is applicable to any type of power plant based on a thermal nuclear reactor but it is not meant to substitute for the detailed technical procedures to be made available at the plant for the purposes of its commissioning.
(e) The Appendix provides guidance on the procedures to be carried out for fuel loading and the Annex elaborates on the tests to be considered for commissioning.

OBJECTIVE

1.3. The objective of this Safety Guide is to make recommendations based on international good practices in commissioning for nuclear power plants, as currently followed in Member States, which will enable commissioning 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 integration into the plant may require comprehensive tests to demonstrate that the plant meets the original or the modified design requirements. The commissioning of modifications 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 covers how the requirements of the commissioning programme, organization and management, test and review procedures and the interfaces can be met between organizations involved in the commissioning activities. It also deals with the control of changes in the commissioning programme and with the documentation required and produced in commissioning.

STRUCTURE

1.6. Section 2 relates to the entire commissioning programme. General matters as well as recommendations for the preparation and approval of the commissioning programme are discussed. Section 3 covers different stages of commissioning in accordance with the practices commonly adopted by States. Organizational matters of the commissioning process are presented in Section 4. The responsibilities of the parties involved in the commissioning process, the interfaces between them, safety management, qualification of the commissioning personnel and organizational aspects of plant handover are covered. Section 5 presents practical issues relating to the implementation of the commissioning programme. Different aspects of the testing which forms the core of the commissioning programme are discussed. The initial fuel loading as well as the achievement of initial criticality are dealt with. Section 6 deals with the documentation to be prepared and produced in commissioning. The Appendix presents specific items to be included in the procedures for fuel loading. The Annex gives a detailed listing of commissioning tests.

2. COMMISSIONING PROGRAMME

GENERAL

2.1. Commissioning, being essential to the subsequent safe operation of the plant, should be carefully planned and executed. The results of commissioning should demonstrate that the requirements and intents of the design and the intent of the designers as stated in the safety analysis report have been met. They should also define the initial characteristics of systems and equipment and provide the source values for operational periodic tests.

2.2. The commissioning should cover all the activities to be performed on structures, systems and components to bring them to an operating mode. It should verify the provisions of the design basis and confirm the assumptions made in the safety analysis report. It should also ensure that there are adequate margins between the design and safety requirements and the actual performance. The commissioning programme may include tests of different types and distinctions should be made between:

(a) Tests which aim at the verification of each functional system including its overall performance.
(b) Tests on new types of equipment.
(c) Tests performed on the prototype plant for a series in order to test the validity of a new concept; subsequent tests on the plants in the series would then just test for conformity.
(d) Tests aimed at acquiring data to validate the code used for the design and to confirm the validity of the limiting safety system settings [3].
(e) Tests to validate operating procedures.

2.3. A detailed programme of commissioning activities should be prepared and responsibilities for implementing and reporting on the various parts of the commissioning programme should be clearly defined. In the planning for commissioning, all activities and organizations involved should be taken into consideration.

2.4. Adequate provision should be made for the allocation of responsibilities for safety at different stages of the commissioning programme, especially after the arrival of fuel at the site. The commissioning programme should indicate the principal points at which reviews and hold points are necessary to satisfy both the operating organization and the regulatory body.

2.5. During commissioning, normal operating procedures, including those for operational periodic tests, should be widely used to validate the applicability of these procedures. The emergency operating procedures (EOPs), which are not used in routine commissioning operations, should also be validated in the commissioning programme, to the extent possible.

2.6. Close liaison should be maintained between the regulatory body and the operating organization throughout the development and implementation of the whole commissioning programme.

MAIN ASPECTS OF THE COMMISSIONING PROGRAMME

2.7. The commissioning programme should be comprehensive and detailed so as to enable assurances to be given that the plant will be commissioned in a safe, efficient and auditable manner. For multiunit plants a separate programme should be produced for each unit. The commissioning programme should separately identify all the tests and related activities necessary to demonstrate that the plant has been properly designed and constructed and can be operated safely.

2.8. The programme should be divided into stages whose number and size will depend upon safety requirements and technical and administrative requirements. The programme should show the planned duration of the activities and their interrelationships, and should include activities that may be necessary in order to provide opportunities for the operating personnel to gain familiarity with the operation of the plant.

2.9. The commissioning programme should be structured so as to ensure that the following objectives are met:

(a) All the tests necessary to demonstrate that the installed plant meets the design intent stated in the safety analysis report are performed.
(b) The tests are performed in a systematic sequence: in particular, tests should be arranged to be progressive, so that the plant is exposed to less onerous conditions before more onerous ones.
(c) The programme provides means of identifying hold points in the commissioning process.
(d) Operating personnel are trained and procedures are validated.

2.10. The programme should also include:

(1) The points at which reviews and hold points are required.
(2) Any applicable requirements of the regulatory body, including the witnessing of specified tests.
(3) The title of each test together with a unique identification.
(4) Cross-references to other documents relevant to commissioning.
(5) Provision for data collection for further use.

2.11. The commissioning programme should include provisions to ensure that operating and maintenance personnel in all disciplines participate to the extent possible in commissioning activities and that the operating procedures are validated to the extent practicable with the participation of plant staff. Designers and other specialists should be involved in formulating tests.

2.12. The 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.

2.13. 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 co-ordination by management.

2.14. The commissioning programme should be prepared in accordance with the quality assurance programme, as recommended in Safety Series No. 50-C/SG-Q on Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations [4].

TESTING IN THE COMMISSIONING PROGRAMME

2.15. Testing, as the core of the commissioning programme, should be sufficiently comprehensive to establish that the plant can operate in all modes for which it has been designed to operate. However, tests should not be conducted and operating modes or plant configurations should not be established if they have not been analysed, if they fall outside the range of assumptions made in analysing postulated accidents in the safety analysis report, or if they might damage the plant or jeopardize safety.

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

(a) Certain systems should undergo prior testing so that they are available for the proper testing of other systems;
(b) Certain systems should be operational to ensure that other systems can be tested without jeopardizing personnel, the plant or nuclear safety;
(c) At any given stage, those tests which are to be considered should be grouped together and completed before the commissioning programme can safely continue.

2.17. The specific procedures should be written in the commissioning programme and 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 for safety should contain checks that all performance levels and operating parameters have been demonstrated for all the operating configurations (normal, transient and accident conditions).

2.18. The commissioning programme should be comprehensive, including statutory non-nuclear tests according to national practice, and should have sufficient scope for redundancy in testing to ensure that there have been no omissions in testing complex systems.

2.19. For identical units in a multiunit nuclear power plant and/or for series of identical plants, it may be acceptable to omit selected tests from those already performed for the units tested previously. The operating organization should ensure that such an action does not jeopardize safety and that it is taken only with the prior approval of the regulatory body.

2.20. If some of the structures, systems and components are common to more than one unit, tests should be conducted to provide assurance that the specified performance requirements of these structures, systems and components can be met for the design intent of each unit.

2.21. Special provision should be made to ensure that the safety of a unit already in operation is not jeopardized in the commissioning tests. Such provisions should include conducting a hazard assessment and obtaining the prior approval of the regulatory body and specific written approval from the manager responsible for the operating unit.

REVIEW AND APPROVAL

2.22. Whatever the organizational arrangements for commissioning of a nuclear power plant, the operating organization should review and approve the commissioning programme.

2.23. The commissioning programme should be submitted for review and approval to the regulatory body, in accordance with national practice.

3. STAGES OF COMMISSIONING

GENERAL

3.1. The commissioning programme of a nuclear power plant should be divided into stages. A review of the test results of each stage should be completed before continuing to the next stage. The review should enable a judgement to be made on whether the commissioning programme should 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 had not been undertaken or had not been completed. (The Annex provides a detailed list of tests to be considered in developing the commissioning programme.)

3.2. On the basis of the broad range of commissioning practices in States, the commissioning process can be divided into the following stages:

— pre-operational tests
— fuel loading and subcritical tests
— initial criticality and low power tests
— power tests.

3.3. In addition, if the sequence of tests in a stage of commissioning is significant for safety, substages may be required by the operating organization or regulatory body[1].

[1] For example in heavy water reactors, the primary heat transport system (and moderator system) may be first commissioned with light water followed by hot conditioning of the inner surfaces of carbon steel piping. The light water is then drained and the system dried thoroughly before the addition of heavy water.

Each stage and substage should be followed by a review before the next stage is started. Before the start of initial criticality tests, low power tests and power tests all the tests at the previous stages should be completed.

3.4. The sequence of tests within each substage should be given in the chronological order in which they are expected to be performed.

3.5. Each stage should include the tasks necessary for the preparation of the succeeding stage and in particular the availability requirements of the systems for the succeeding stage.

3.6. To the extent practicable, the tests should be of sufficient duration to allow the systems and components under test to reach their normal equilibrium conditions, thus reducing the probability of failure in the early stages of operation.

3.7. Careful consideration should be given to the demonstration of the capability of the systems and components to withstand failures and/or malfunctions that previous experience has shown may occur over the expected plant lifetime.

3.8. The relevant safety system settings and alarm settings, including those of radiological protection instruments, should be specified at the appropriate commissioning stages.

PRE-OPERATIONAL TESTS

General

3.9. Before the commencement of the initial testing of any structure, system or component the following steps should be taken:

(a) Construction activities associated with the system, including quality assurance, should be completed and documented to the extent necessary and practicable.
(b) It should be ensured that the equipment is ready for operation: inspection for proper fabrication (including welding) and cleanness, checking of electrical and protective devices, adjustment of settings on valve torque limiting devices, calibration of instruments, verification of operability of instrument loops and required response times, adjustment and settings of process controllers and limit switches.
(c) It should be ensured that test equipment is operable and properly calibrated and that response times are as required.

3.10. A review should therefore be undertaken before the commencement of this stage to ensure that the tests have been carried out on those systems and components required for this stage for which the construction group is responsible (para. 4.27). 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 started.

3.11. A satisfactory pre-operational test should take into account the proper sequence of tests of electrical systems, instrumentation systems and other service systems such as cooling water systems and fire protection systems in order to ensure the availability of the necessary services for the implementation of the entire commissioning programme.

3.12. The stages of the pre-operational tests may be divided into the following substages:

— cold performance tests
— hot performance tests.

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

Cold performance tests

3.13. Cold performance tests include the initial startup of fluid systems and support systems. The objective of this stage is to obtain initial operational data on equipment, ensure compatibility of operation with interfacing systems and verify the functional performance of these systems. The tests usually include pressure testing of the primary and secondary systems.

3.14. 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 as part of the commissioning programme in this substage.

Hot performance tests

3.15. 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.

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

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

3.18. The operating personnel should take the opportunity at this substage to use and verify the operating procedures.

FUEL LOADING AND SUBCRITICAL TESTS

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

3.20. With the core loaded and the reactor maintained in a subcritical condition, a series of performance tests should be carried out. These should include checks on coolant flow rates, instrumentation, rod control mechanisms, automatic rod insertion and other important features of the primary circuit.

3.21. The beginning of initial fuel loading is the commencement of operation; from this point onwards the relevant safety requirements for plant operation apply [1]. Responsibility for meeting these safety requirements should usually rest from this juncture with the plant manager.

INITIAL CRITICALITY AND LOW POWER TESTS

3.22. 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:

(a) The performance of the reactor core is commensurate with predictions made in the core design.
(b) The reactor core is in a proper condition for operation at higher power levels and the characteristics of the reactor core coolant, reactivity control systems and shielding are appropriate.
(c) The reactor physics parameters are in accordance with predictions made in the 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 serious discrepancy between measured values of reactor physics parameters and other parameters and values used in the safety analysis report. The power levels at this stage should be the lowest that give reliable and stable measurements and which enable the conditions required to perform the specified tests to be achieved. Special startup instrumentation should be provided if necessary.

3.23. Where necessitated by the reactor design, system flow tests and cold and hot tests of appropriate duration should be made with the loaded core. Appropriate tests of fuel handling equipment should be completed and radiological surveys and functional tests of radiation protection equipment should be made.

3.24. In these tests the trip limits of the nuclear flux channel for the reactor protection system should be set to a conservative level.

POWER TESTS

3.25. 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 which can be carried out only at power.

3.26. This stage of commissioning consists of a step by step approach to full power and full power tests. At each substage a series of tests will be carried out at specified power levels. Typical steps may be 10, 25, 50, 75, 90 and 100% of full power.

3.27. 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.

3.28. A review should be carried out at the end of the stage to confirm whether the operational limits and conditions are adequate and practicable [3], and to identify any constraints on the operation of the plant that the commissioning tests have shown to be necessary.

4. ORGANIZATION AND MANAGEMENT

COMMISSIONING ORGANIZATION

Organizational arrangements

4.1. Organizational arrangements should be in place to achieve the safety objectives of commissioning in accordance with the programme outlined in Section 2. They should represent a convenient and practical working scheme which allows optimum use of available personnel, materials and methods, and which enables assurances on safety to be obtained.

4.2. The principal activities performed in commissioning may be divided into three categories:

(1) Those associated with the final stage of construction and installation of the plant;
(2) Those specific to commissioning, including safety reviews;
(3) Those associated with the operation of the plant.

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

— construction group
— commissioning group
— operating group.

4.4. There may be other representatives participating in commissioning activities, such as representatives of the designers, the construction group, the manufacturers and the regulatory body. These representatives should collaborate with the aforementioned groups as appropriate. In particular, the designers and manufacturers should provide adequate and complete information to the groups. The designers should also review the commissioning data and should certify that the performance meets the design intent.

4.5. There may be many ways in which the construction, commissioning and operating groups could be formed by different organizations. This may depend upon the industrial practice and experience of nuclear power in the State, 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 contract the commissioning activities to another organization, it should be made clear that the ultimate responsibility for safety remains with the operating organization.

4.6. The construction group should ensure that the installation has been completed in accordance with specifications. 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 plant in accordance with the assumptions and intent of the commissioning programme.

4.7. 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 in order to ensure that as many operating personnel as possible gain field experience and to establish an 'institutional memory' of the plant.

4.8. Since construction, commissioning and operating activities overlap, in the arrangements made in respect of utilization of personnel among the construction, commissioning and operating groups, it should be ensured that responsibilities remain clear at all times.

Safety management

4.9. The commissioning phase should foster a safety culture [5], which should be maintained throughout the operating phase.

4.10. Specific consideration should be given to the arrangements used by the organizations participating in the commissioning process for the management of safety [6] in order to enhance safety culture and achieve good safety performance. Safety management should comprise all aspects of safety, such as industrial safety, fire protection, radiation protection and nuclear safety.

4.11. The following specific aspects should be reflected in the safety management system for the commissioning phase:

(a) The interface and appropriate links to ensure that commissioning is in accordance with the requirements of the safety analysis report;
(b) The interface between the various organizations participating in the commissioning process;
(c) The transfer of the responsibility for safety from one participating organization to another;
(d) The discharge of responsibilities for safety owing to the gradual handover of commissioned systems and components of the plant.

Organization of the commissioning group

4.12. The commissioning group and the special arrangements made to ensure proper co-ordination of commissioning activities should be established early enough to allow all these activities to be identified and adequate preparations to be made.

4.13. The commissioning group should be headed by a commissioning manager who has had experience with nuclear power plants. The commissioning manager should be appointed well in advance of the actual commissioning work so as to be able to make the necessary arrangements for scheduling and organizing work units, work plans and other resources.

4.14. Specific test teams should be established to perform commissioning tests. The number and composition of these teams should be dependent on matters such as:

— the number and complexity of the systems to be tested
— the scheduled target dates
— the workload
— the skills necessary to perform the tests
— the staff available.

4.15. Each test team should be led by a test team leader with appropriate experience.

4.16. The commissioning manager should prepare suborganizational charts showing the allocation of responsibilities for staffing and systems to each test team leader. These charts should be made available to the other groups in order to help ensure effective co-ordination of the work.

4.17. A planning and scheduling unit should be set up in the commissioning group to monitor and report on the progress of commissioning in all its aspects, including the issuing of commissioning reports and transfer certificates for systems.

FUNCTIONS AND RESPONSIBILITIES IN COMMISSIONING ACTIVITIES

General

4.18. Responsibility for 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 loading or at some other appropriate hold point. Whatever the arrangement, the organization or individual responsible for commissioning should be accountable to the organization or individual responsible for compliance with the licence for the following:

(a) Demonstration that the plant behaves in accordance with the design intent,
(b) Confirmation that the plant has been tested within the design limits only,
(c) Ensuring that safety requirements are observed while the commissioning process is being conducted.

4.19. The detailed listing of functions and responsibilities in paras 4.20–4.31 should be viewed as illustrative only; actual functional responsibilities may be assigned according to national regulations and practice.

Operating organization

4.20. The operating organization, as the organization authorized by the regulatory body to operate the plant, should be the overall controlling and co-ordinating authority for overseeing the safe and satisfactory completion of all commissioning work.

4.21. When commissioning activities are conducted under the responsibility of the contractors, the operating organization should make the necessary arrangements to review and approve these activities at all stages.

4.22. Appropriate actions should be taken by the operating organization at the commissioning stage to promote and foster the development of safety culture at the plant. Attributes such as personal dedication, safety consciousness and a questioning attitude should be fostered at the pre-operational phase so as to become habitual in the subsequent operational stage.

4.23. The responsibilities of the operating organization should include:

(a) To control, review and co-ordinate the activities of the construction, commissioning and operating groups in an effective manner;
(b) To ensure that the commissioning procedures are prepared, reviewed and approved by personnel with appropriate technical backgrounds and experience;
(c) To arrange for the required submissions to the regulatory body at the approved stages and to comply with its requirements;
(d) To establish procedures for ensuring the co-ordination of commissioning activities, account being taken of the views and experience of members of the construction, commissioning and operating groups as well as other participants such as those from the designers, the manufacturers and the consultants and quality assurance personnel;
(e) To ensure the maintenance of adequate numbers of properly trained, experienced, qualified and, where required, authorized personnel in the construction, commissioning and operating groups;
(f) To receive and disseminate the requirements of and information from the regulatory body.

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

- To review and approve the commissioning programme;
- To co-ordinate the provision of the personnel, materials and equipment necessary for commissioning;
- To identify and monitor the transfers of responsibilities;
- To monitor the implementation of the commissioning programme;
- To resolve problems between groups and interface problems;
- To review and approve test procedures;
- To consider the safety aspects of proposed changes;
- To determine whether tests and stages have been properly completed;
- To remedy those defects detected in commissioning tests;
- To maintain liaison with the regulatory body according to national regulations and practice.

Operating group

4.25. The responsibilities of the operating personnel at the plant in relation to commissioning should be as follows:

- To satisfy themselves that the systems which are transferred comply with specified performance requirements, the design intent and safety requirements;
- To accept responsibility for the transferred systems;
- To participate in the commissioning activities;
- To become competent in the methods of operation of the plant;
- To carry out operation and maintenance with competent staff using approved techniques to meet the needs of the commissioning programme.

Commissioning group

4.26. The responsibilities of the commissioning group should include the following:

— To plan in advance 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, plant handover documents 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 in commissioning are analysed so that the experience gained can be fed back to the designers or the operating group;
— To verify that the installation of structures, systems and components has been satisfactorily completed and codified for proper identification;
— To ensure that the prerequisites for the commissioning programme have been satisfied and that pre-operational tests such as 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 for safety (including radiological protection and safety);
— To ensure that the systems are commissioned safely and to confirm that the written operating procedures are adequate;
— To implement all the 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 items) for which responsibility has been accepted;

— To direct the operation of systems in the commissioning programme and to update operational flow sheets and operating and maintenance instructions, as well as procedures based on experience in commissioning;
— To issue commissioning reports on tests;
— To ensure that a procedure is in place to control the calibration of test and measurement equipment;
— To establish a procedure to ensure that all participants in the commissioning process are suitably qualified and experienced;
— To ensure the configuration management, maintaining consistency between as-built drawings and procedures and physical configuration and the design requirements;
— To ensure that design changes are requested, reviewed and implemented when design criteria are not met or when they fall short;
— To establish a procedure for controlling temporary changes to 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 deficiency detected in commissioning tests in order that corrective actions can be taken;
— To maintain a record of limiting conditions in commissioning;
— To ensure that plant performance is in accordance with the design intent, including all aspects of radiological protection and safety;
— To certify that the commissioning programme has been satisfactorily completed;
— To transfer the responsibility for operation of the commissioned systems and/or plant to the operating group using a system of documents such as transfer certificates;
— To establish and implement procedures that 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 plant experience, typically by utilizing the appropriate personnel, as necessary, for commissioning activities;
— To establish procedures for analysing the results of tests and for producing test reports and test certificates.

Construction group

4.27. The responsibilities of the construction group in relation to the commissioning process should include the following:

(a) To ensure that the installation of structures, systems and components has been completed in accordance with design requirements and specifications;
(b) To make suitable arrangements for surveillance and maintenance to prevent deterioration after the completion of installation and before the handover;
(c) To issue certificates of completion of installation giving the necessary assurances to the commissioning group;
(d) To provide, for use as baseline data, as-built documentation of installation and test certificates, highlighting design changes and concessions;
(e) To transfer the installed systems to the commissioning group using a system of documents such as transfer certificates;
(f) To correct deficiencies in installation detected in commissioning.

Regulatory body

4.28. The regulatory body should prepare a programme of review and assessment of the commissioning process. Before the start of commissioning, the regulatory body should review and approve the commissioning programme as required by national practice. Where appropriate, hold points should be established in order to assess test results before regulatory authorization is given to proceed.

4.29. Before authorizing the loading of nuclear fuel or initial criticality, the regulatory body should complete as appropriate the review and assessment of such aspects as:

— The as-built design of the plant;
— The results of pre-operational tests;
— The operational limits and conditions (OLCs);
— The specific limits and conditions for operation during the commissioning of the plant from first criticality to full power;
— The adequacy of operating procedures and instructions, especially main administrative procedures, normal operating procedures and EOPs;
— The staffing and management structure of the plant and arrangements for ensuring that qualification requirements are fulfilled and training is performed;
— The quality assurance programme for all commissioning, operation and maintenance activities;
— The records and reporting system;
— The radiation protection programme;
— Emergency preparedness;
— The arrangements for periodic testing, maintenance, inspection and surveillance;

— The arrangements for configuration control, especially control of plant modifications;
— The measures for the accounting for fissile and radioactive materials;
— The adequacy of the arrangements for physical protection important to safety;
— The adequacy of support for technical procurement, safety and other matters at the operating organization or at the site, if appropriate;
— The fulfilment of the applicable requirements in respect of safeguards.

4.30. Before licensing and/or authorizing routine operation at full power, the regulatory body should complete the review and assessment of:

- The results of commissioning tests and their analysis;
- The safety analysis report or the equivalent.

Other participants in the commissioning activities

4.31. 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:

(a) To co-operate with the commissioning group by means of active participation when required;
(b) To provide specialist knowledge, expertise and relevant experience from plants already commissioned;
(c) To provide baseline data and all necessary information;
(d) To provide a safety assessment when necessary;
(e) To participate in the analysis of discrepancies and unexpected events;
(f) To design modifications in order to rectify design deficiencies and to provide complete documentation of the modification, including requalification tests.

INTERFACES BETWEEN PARTICIPANTS IN THE COMMISSIONING PROCESS

General

4.32. Many activities should be performed in parallel with the commissioning of the plant, such as those relating to construction, operation and maintenance.

4.33. The interfaces between these activities should be adequately managed to ensure the protection and safety of the plant and personnel and to ensure that the commissioning programme is not impaired.

4.34. Appropriate work control processes should be established to co-ordinate the activities of all groups involved in commissioning and to cover the major work activities, including post-work testing. This process should provide for the proper channelling of the work to the person responsible for the system and for ensuring notification and awareness in the control room of all the work activities that are in progress.

4.35. All the organizations involved in the commissioning process should achieve and sustain the same level of safety culture, which should be an inherent feature of the operating organization.

Interface between construction activities and commissioning activities

4.36. Clear and well understood lines of authorization and communication between construction and commissioning activities should be established and documented so as to manage a rigorous work prioritization policy. The lines of communication should support the commissioning schedule and should comply with the agreement on the scope of activities in both organizations, in particular at the interfaces.

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

4.38. The following particular areas of consideration are appropriate to the interface between construction and commissioning:

- Procedures for transferring structures, systems and components for commissioning;
- Prerequisites for the start of the commissioning programme;
- Special precautions necessary for the commissioning of partly installed systems (see also para. 4.26 concerning the responsibility of the commissioning group for repeat testing of systems that have been commissioned initially as partially installed);

- The sequence of transfer of structures, systems and components consistent with commissioning priorities;
- Methods of identifying special technical, operational or staffing restrictions necessary as a result of partial completion of construction activity;
- Continual review of the as-built data with regard to any possible impact on commissioning;
- Return of systems for rectification of defects arising from commissioning tests;
- Testing of equipment following intervention by the construction group;
- Certification for first energization of systems to establish control under the safety or permit rules.

Interface between commissioning activities and operating activities

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

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

(b) Baseline data derived from commissioning, such as the issuing of formal test reports and a statement of the existing radiological conditions.

(c) Changes in responsibility for safety including the nomination of responsible persons.

(d) Modifications to the plant and to the procedures.

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

(f) Conditions for access of personnel, with account taken of delineation between systems already in operation and those being tested.

(g) Control of temporary procedures and equipment available during commissioning but not appropriate for normal operation; for example, special startup instrumentation or duplicate safety keys and authorization for the use of jumpers and lifted leads.

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

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

(j) Procedures for radiological monitoring and protection of site personnel and for keeping records of occupational exposures deriving from the commissioning in accordance with national regulations.

(k) Training in radiological safety and authorization of commissioning personnel to work in the controlled area.
(l) Reassessment of routine operating and maintenance instructions and procedures in the light of experience gained in commissioning.
(m) Development of arrangements and instructions for emergency preparedness.
(n) Keeping records during commissioning of information that could have implications for decommissioning, and subsequent handover of these records to the operating organization (e.g. records of spills or other unusual occurrences that could have long term effects).

4.40. There should be plans to include operating personnel in commissioning activities at the plant at all levels, thus providing the operating staff with an opportunity to become familiar with and gain experience of the plant. This approach to training and preparation of the operating staff during commissioning will contribute towards the assurance of safety during the initial operation of the plant.

4.41. Procedures for operating and periodic testing should be used as far as the conditions of the plant will allow in the commissioning phase so as to validate them prior to initial loading of the core. Interorganizational arrangements should be made to schedule this activity so as to ensure that procedures, including operating, maintenance and surveillance procedures, are adequately validated.

4.42. Personnel should adhere to normal operating rules such as those relating to access to the control room, control of information, control cabinets and switchboards, communications with the control room about abnormalities and changes in plant configuration. The need for adherence to normal operating rules should be re-emphasized to personnel after the core has been loaded.

ASSESSMENT

4.43. The self-assessment of management should be implemented by the operating organization in order to evaluate the effectiveness of the commissioning programme in all areas for which the management has responsibility. The purpose of management self-assessment should be to evaluate known performance issues, to identify management aspects contributing to these issues and to make improvements. Guidelines for the conduct of management self-assessment can be found in Ref. [4], in particular Safety Guides Q5 and Q12.

4.44. An independent assessment should be conducted in order to determine the effectiveness of management processes and the adequacy and quality of work performance. The independent assessment may include internal and external audits, surveillance, peer evaluation and technical reviews. The independent assessment should be performed by a suitable team of experienced personnel who do not have direct responsibilities in the areas being assessed. Typical subjects to be addressed by independent assessment of the commissioning programme should include, but not be limited to, the following:

- interfaces
- safety management
- temporary modifications
- plant labelling
- housekeeping and material conditions
- configuration management
- the system for walkdowns
- the work control system.

For further guidance on independent assessment see Safety Guide Q5 in Ref. [4].

4.45. In the system of document control that is established, self-checking features (para. 6.4) should be adopted so as to minimize the possibility of interruptions in the commissioning process.

4.46. The operating organization should take the necessary action to remedy in a timely manner any deficiencies revealed in the assessment process.

QUALIFICATION AND TRAINING

4.47. Personnel engaged in commissioning activities should be suitably qualified and experienced for the level of responsibility and importance to safety of their work. The necessary level of qualification and experience should be specified for each position in the organization. In addition, provision should be made for training personnel who participate in the commissioning process in certain aspects of the plant site and methods of working.

4.48. A training programme should be developed to cover these aspects. The subjects that should be considered are:

- 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 importance of reporting incidents;
- Methods of and techniques for commissioning;
- Safety culture;
- Nuclear safety, industrial safety, fire protection and radiation protection;
- Design criteria, technology and operational limits and conditions (or their equivalents) for the plant;
- Environmental protection and management including waste management.

4.49. Designers, vendors, main contractors and operators should be encouraged to participate in the training programme because of their close interaction during this phase.

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

4.51. 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.

4.52. Aspects of safety culture should be included in the training programme. It should be emphasized in the training programme that individuals should be aware of the significance of their duties and the possible consequences of mistakes arising from misconceptions or lack of diligence. Commissioning and construction personnel in particular should understand their functions in establishing a sound basis for the subsequent operation and eventual decommissioning of a plant.

4.53. If any major incidents occur during commissioning, training should be systematically reassessed. Experience gained in commissioning should be appropriately incorporated into the training material. Quality objectives and safety objectives should be emphasized.

4.54. 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. [7].

MAINTENANCE DURING COMMISSIONING

4.55. From construction to commissioning and finally to operation, the plant should be adequately monitored and maintained. It should be subject to the required periodic tests and inspections in order to protect equipment, to support the testing phase and to continue to comply with the safety analysis report. Historical records of operation and maintenance should be kept from the time of initial energization and operation of each plant system, and provision should be made to transfer these records eventually to the operating organization.

4.56. The organization for maintenance during commissioning should be adequately described and documented so as to be clear to all the parties involved.

4.57. The scope of the responsibilities of the construction and operating groups in relation to maintenance during commissioning should be clearly identified. The organization established for maintenance during commissioning should ensure that the maintenance group of the operating organization becomes actively involved at all levels in the organization for maintenance during commissioning. The participation of personnel from the instrumentation and control section in particular should be encouraged. Recommendations and guidance on maintenance activities can be found in Ref. [8].

PLANT HANDOVER

4.58. Plant handover is the transfer of responsibilities for the plant. This should include structures, systems and components, items of equipment and documentation, and may include personnel. Depending on the plant organization and the framework for handover, two separate types of transfers may be identified: 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 activities should be documented.

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

4.60. The most important transfer of responsibility is the transfer of responsibility for safety. Special care should be taken to ensure that responsibilities for personnel, plant and safety are clearly defined and rest with the appropriate organization (see also para. 4.65). From the time of the arrival of nuclear fuel at the site, responsibility for safety should rest with the operating organization.

4.61. Responsibility for systems should be transferred gradually to the operating group as soon as the testing before the introduction of fissile and radioactive material (pre-nuclear tests) has been performed and the results approved. In this way operating personnel can carry out the inspection prior to acceptance in a thorough manner. Some systems (e.g. electrical systems) may be transferred to operating personnel with responsibilities for operation only before the pre-nuclear tests have been performed and the results approved.

4.62. 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 in order for the plant personnel to be able to make a comprehensive review of every package. Account should be taken in these transfers of how the responsibilities for testing after fuel loading, at initial criticality, at low power and at power escalation are assigned.

4.63. 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, flushing records and cleaning records: a master strainer logbook used for equipment testing and flushing of piping.
— Acceptance packages from the construction (including welding inspection records).
— As-built diagrams, electrical diagrams, instrumentation and control diagrams and flow diagrams.
— Documentation of pre-nuclear test procedures and report data sheets.
— Failure reports and incident reports.
— Documentation on temporary modifications, lifted leads and jumpers and software modifications.
— Equipment isolation records and work permit records.
— Records of preventive and corrective maintenance.
— Surveillance records.
— Records of field changes and design changes.
— Pending item lists including defects, omissions and weaknesses carried forward from the previous handover.
— Vendors’ manuals and set point books.

4.64. Engineering personnel should be designated to conduct the review to be carried out by the operating organization receiving the handover package. In performing the review, meetings should be held and plant walkdowns should be carried out by representatives of the organizations involved in the handover process.

QUALITY ASSURANCE

4.65. The operating organization should be responsible for establishing and implementing a quality assurance programme for commissioning that is effective and is in accordance with national and international standards. The operating organization may delegate to contractors part or all of the activities for planning, establishing and implementing the quality assurance programme for commissioning but should retain responsibility for its effectiveness.

4.66. 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. Arrangements should be made to ensure that these procedures are reviewed and approved before issue and that their subsequent amendment is controlled. Recommendations and guidance on quality assurance in commissioning can be found in Ref. [4], in particular Safety Guide Q12.

EMERGENCY ARRANGEMENTS

4.67. The operating organization should be responsible for ensuring that an appropriate organizational plan is in place for managing emergencies in the commissioning phase. Appropriate emergency arrangements should be established from the time that nuclear fuel is brought to the site, and complete emergency preparedness arrangements should be in place and should be tested before the commencement of fuel loading.

4.68. In preparing emergency arrangements for the commissioning phase, account should be taken of the fact that non-nuclear hazards such as fire could arise while nuclear fuel is on the site.

4.69. A potential nuclear hazard could arise if an operating unit is adjacent to another unit under construction or commissioning. If this is the case, emergency arrangements should be made for the protection of the construction personnel and the commissioning personnel. Account should be taken in the emergency arrangements of any other local hazards.

4.70. All the parties involved in the commissioning programme should be trained appropriately to cope with any anticipated emergency at the plant being commissioned.

4.71. Recommendations and guidance on detailed instructions and procedures for actions to be taken in the event of a nuclear or radiological emergency are given in Ref. [9].

FEEDBACK OF EXPERIENCE FROM COMMISSIONING

4.72. 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'[2] in the commissioning phase. Experience gained at this stage should be fed back into the training programme for operating and commissioning personnel. The lessons learned should be used in the improvement and development of the commissioning programme, operating procedures and instructions. In addition, consideration should be given to the need for any changes in the design.

4.73. In the preparation of the commissioning programme, consideration should be given to experience gained around the world about which information is available through industrial bodies.

[2] A 'near miss' is a potentially significant event that could have occurred as the consequence of a sequence of actual occurrences but did not occur owing to the plant conditions prevailing at the time.

5. IMPLEMENTATION OF THE COMMISSIONING PROGRAMME

TEST PROCEDURES

General

5.1. All commissioning tests should be performed in accordance with authorized written procedures. The preparation of test procedures, including their verification and approval, should be defined by an administrative procedure. The level of review should reflect the importance to safety of the 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.

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

5.3. The procedures should be subject to a thorough verification and approval process in which the regulatory authorities and the operating organization should participate. The designers should also participate in the approval process, in particular in reviewing the validity of the acceptance criteria.

5.4. The test procedures should follow normal plant operating procedures to the extent practicable, so as to verify them. If necessary, the normal operating procedures should be amended for use during commissioning. This will permit the operating personnel to become familiar with them.

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

Contents of procedures

5.6. Although the format of procedures may vary from plant to plant, the contents of test procedures should include, but not be limited to, the following.

Introduction

5.7. A summary should be given of the main test objectives and of the safety aspects to be demonstrated. The system to be tested should be identified and the anticipated test results 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

5.8. The objectives of the test and the methods by which they are to be achieved should be stated. Some commissioning tests will be intended to demonstrate that each of several input signals will produce one or more desired actions. These input signals and the corresponding actions should be identified. More generally, tests are conducted to confirm the ability of systems or of the plant to perform within established values of parameters, which should be stated before the tests.

Limiting criteria

5.9. Applicable operational limits and conditions, including appropriate temporary operational limits and conditions, should be stated.

Prerequisites and initial conditions

5.10. 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

5.11. The way in which the system to be tested is required to be brought up to test conditions should be specified and details of the test procedures should be provided, preferably in a step by step format. This should include any temporary changes or abnormal alignments of the system or the adjacent systems.

Acceptance criteria

5.12. The acceptance criteria should be stated and this statement should wherever possible be quantitative as well as qualitative (for fuel loading, for example).

List of instrumentation and special test equipment

5.13. 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

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

Special precautions

5.15. Special precautions necessary for the safety of personnel and the security of equipment should be clearly described in the test procedure. In addition, any special precautions necessary to ensure safety should be stated.

Completion of test

5.16. Provision should be made for a statement by the individuals responsible to indicate that the test has been satisfactorily completed and that the systems have been returned to normal conditions. 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

5.17. 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

5.18. 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

5.19. The test procedures should include arrangements for tabulating data and test results. Test sheets should be standardized and each sheet should be signed by the collector of the data. Chronological recording is desirable (test data, date and time).

5.20. Techniques of analysing data and the results of measurements should be stated, including the manner of obtaining verifications, and the extent of the check calculations made should be reported in the results.

TEST RESULTS

Review and approval of test results

5.21. The purpose of a review is to provide assurances that the testing performed demonstrates that the performance of the systems tested is in accordance with the design intent and that any operating constraints have been identified. It should ensure that all necessary data have been obtained and analysed, and that a technical evaluation and report have been completed. The review should also provide assurances 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. The evaluation of the test results should include a comparison with the acceptance criteria and should be carried out by the commissioning group, the designer and the regulator. The objective is to clarify whether the design intent has been met.

5.22. Personnel assigned to carry out reviews should have had adequate experience in their individual specializations. Consultants may be used for dealing with particular problems.

Documenting the test results

5.23. Documents should be prepared and issued during the progress of the commissioning activities in order to certify the performance of the tests and to provide the required authorizations for the continuation of the programme, in accordance with the procedures established by the operating organization. The following types of documents may be used.

Test certificate

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

Stage completion certificate

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

Approval certificate

5.26. An approval certificate is issued by the operating organization to permit the programme of testing to continue from one review stage to another. Where required, the operating organization should obtain approvals from the regulatory body.

5.27. The reports mentioned in para. 5.33 can also serve as valid test, stage completion and/or approval certificates, as the case may be, provided that they contain all the information required.

Stage completion

5.28. At the end of a stage, the results of 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 national regulatory practices, the regulatory body may be involved in the review and approval of the results of a specific stage. All test reports for the stage should be completed and all test certificates should be signed before this review.

5.29. Reviews should 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.

5.30. 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 expeditiously. To this end, reviews of test results should be undertaken and test results should be accepted at suitable times during the progress of testing within 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 (Section 6). 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.

5.31. 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 with the requirements of the regulatory body.

Reporting

5.32. The commissioning group (para. 4.26) should report the test results to the operating organization and, as required, to other participants in the commissioning programme. Although it may be expedient 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 submitted. These formal reports should be retained for the purposes of record keeping. In addition to individual tests, stage test reports and a final station commissioning report should be prepared.

5.33. Formal reports for each test should be prepared by the individuals responsible and should be approved by the commissioning group. The format of a report may vary but normally it should include:

(a) Introduction;
(b) References to appropriate test procedures;
(c) Summary of test objectives;
(d) Conduct of the test, including the initial and final states of the plant, the actual limitations experienced, and the problems encountered and the actions taken to overcome them, including any modifications to the plant or to the procedures;

(e) Concise description of any special test equipment used;
(f) Summary of data collected and analyses of the data;
(g) Evaluation of results, including statements that the acceptance criteria have been met;
(h) Conclusions;
(i) Identification, cross-references and a distribution list (para. 5.18).

INITIAL FUEL LOADING

General

5.34. The plant should be prepared well in advance for the initial fuel loading. The prerequisites concerning testing, systems, equipment, documentation and personnel should be established. These prerequisites, including satisfactory performance of the integrated plant systems, should be clearly described 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 initiation of fuel loading.

5.35. The requirements and procedures should be in place to test the fuel loading machine and/or any other tool or system necessary before the commencement of fuel loading. The personnel responsible for loading should be qualified and trained in advance. Proper training should be carried out on the fuel loading machine, including operations in the reactor cavity and spent fuel pit, using dummy fuel assemblies. Operators of the fuel loading machine should be licensed in accordance with local regulations.

5.36. 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 for the timely indication of potential inadvertent criticality. Adequate means should be available to restore the shutdown margin in the event of an inadvertent approach to criticality.

5.37. Initial fuel loading should be authorized only when all pre-operational tests required by the operating organization and the regulatory body have been performed and results have been obtained that are acceptable to both parties.

5.38. Initial fuel loading should be supervised by duly authorized engineers, and any changes occurring in the reactor should be reported immediately to the control room personnel.

5.39. For the fuel loading procedure, the following should be required, as appropriate: periodic recording of data; audible indication of flux increases; monitoring of neutron count rate instruments when fuel is being inserted and/or when other operations are performed that could affect core reactivity. In addition, subcriticality checks should be performed at regular steps in the loading procedure in order to determine 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. If actual measurements deviate from the predicted values, procedures should require loading to be stopped until the circumstances have been analysed, the reasons for the deviations have been determined and any appropriate corrective action has been taken. (The Appendix presents further guidance on the details to be included in the procedures for fuel loading.)

5.40. During fuel loading operations, the exact position of each core element should be clearly indicated in the loading procedures or loading plan and this should be documented. At the end of fuel loading, the position of each core element should be independently confirmed and documented.

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

5.42. 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 subcriticality shall be ensured.

ACHIEVING INITIAL CRITICALITY

5.43. 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, that the reactor is in the proper condition for startup, and that the appropriate approvals to proceed to this stage of commissioning have been obtained.

5.44. Before the approach to criticality is started, operability of the automatic reactivity shutdown devices shall be ensured and appropriate startup monitoring instrumentation shall be available to initiate shutdown devices when necessary.

5.45. 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 can be continually checked. The sequence and magnitude of changes in reactivity, made by means of removal of the absorber and/or adjustment of the moderator level, should be defined in the procedures.

5.46. 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 the minimum level compatible with the demands of the tests scheduled in this substage.

5.47. 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 (i.e. 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.

DEVIATIONS DURING COMMISSIONING

General

5.48. During commissioning, changes to the 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.

Modifications

5.49. 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.

5.50. 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.

5.51. 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 authorized by means of a change notice.

5.52. 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 in order to ensure safe performance of the test.

5.53. Any changes to the approved test procedures should be controlled by means of an appropriate administrative procedure.

5.54. 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.

5.55. Additional guidance on arrangements in connection with anticipated plant modifications during the commissioning stage can be found in Ref. [2].

Unexpected test results and occurrences

5.56. In spite of adherence to good design, approved construction and commissioning procedures, and good working 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 decide on the corrective actions to be taken.

6. DOCUMENTATION

6.1. Relevant commissioning documentation should include, but not be limited to, the following:

(a) Commissioning schedules, procedures and reports: commissioning programmes and schedules, test procedures, data collection sheets, installation completion certificates, standard test sheets, summary test reports, records of deficiencies noted during commissioning and corrective actions taken, test reports, test completion certificates, system transfer certificates and stage completion certificates.
(b) Documents providing baseline data and additional information for commissioning: vendor specifications, design basis and safety analysis report and records of subsequent changes to any of these documents, requirements of the regulatory body, licences and other relevant statutory documents.
(c) Documents whose contents are to be verified during commissioning: documents containing operational limits and conditions and instructions and procedures for operation and maintenance, and other documents prepared for operation.
(d) Other documents relevant to commissioning: records relating to location of fuel assemblies and other nuclear materials, procedures for the safety of personnel, procedures for radiological protection and associated records.

6.2. 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 appropriate modifications have been made,
- Assurance to the operating organization that commissioning is proceeding in accordance with all requirements,
- Documentation in accordance with the quality assurance requirements,
- Records that need to be available throughout the lifetime of the plant,
- Assurance to the regulatory body that its requirements are being met.

6.3. 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 approved by the operating organization.

Recommendations and guidance on the production, extent and control of commissioning documents are presented in Ref. [4].

6.4. Commissioning documents are normally provided by the commissioning group, which should ensure that methods for the preparation, safe keeping, retrieval and review of documents are specified. For document control purposes, an integrated and consistent referencing procedure should be established covering all commissioning documents. Special methods of identification of important documents with self-checking features to facilitate reviews and audits of records should be considered. Document control procedures should be in place to ensure that those persons participating in commissioning activity are provided with approved procedures.

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

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

A.2. The following activities and checks must 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 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 startup instrumentation, in terms of proper calibration, location (source–fuel–detector geometry) and functionality, including aural 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 of the shutdown margin by making conservative assumptions about conditions and by locking off power supplies to prevent the inadvertent 'removal' (reduction) of negative reactivity;
- Operability of fuel handling equipment, including on-site trials of fuel handling equipment using dummy fuel assemblies;
- Status of protection systems, interlocks, mode switches, alarms and radiation protection equipment as prescribed; high flux trip points set for a relatively low power level (approximately 1% of full power) for operability of control rods

during fuel loading, with the alarm and trip settings of other protection channels set to low values;
- Availability of criticality precautions;
- Composition of the fuel handling crew, and their duties and responsibilities in the event of emergencies;
- 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 taken to prevent criticality and physical damage;
- Loading sequences and patterns for the different types of fuel (in terms of grades of enrichment and poisoning), control rods, and other absorbers and components;
- 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;
- 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 seating 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;
- 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 to be taken during periods when fuel loading is interrupted, especially those pertaining to flux monitoring;
- A method of maintaining adequate communication between the control room and the loading station;
- The minimum number of personnel necessary to load fuel;
- Specified permitted working time of the personnel;
- Establishment of criteria for cessation of 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 must not 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;
- In cases that any stated limits have been reached or exceeded, actions to be taken or approvals to be obtained before routine loading may be resumed.

Annex

DETAILED LISTING OF COMMISSIONING TESTS

INTRODUCTION

A–1. This Annex provides a detailed listing of tests to be considered in the development of a commissioning programme. These lists of tests are neither complete nor applicable to all reactor types. The 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[1]:

(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 coastdown.

(d) Piping and vessels: pressure tests; leaktightness, cleaning and flushing; clearance of obstructions; support adjustments; proper gasketing; bolt torque; insulation; filling and venting.

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[1] Note that some items are applicable only to important or special components, and some tests may be included in the pre-operational stage itself.

(e) Instrumentation and control: voltage, frequency, current, circuit breaker operation, busbar transfers, trip settings, operation of prohibiting and permissive interlocks, calibration.

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 those 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 the 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 prestressed 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 tests of the moderator channel system, including the cover gas system, the auxiliary systems for chemical control and the 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, adequacy of sampling and analytical techniques, operation of heaters and trace heating; operation of instrumentation, controls, interlocks and alarms; rate of injection into and dilution from the bulk system; redundancy, electrical independence and operability of system components; correctness of failure mode on loss of power to system components.
(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 shut-off system: normal operation and shutdown capability including cooling requirements; scram times and, where applicable, friction tests; appropriate performance of inhibition 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 shut-off drive systems with other systems such as automatic reactor power control systems and refuelling equipment; correct failure mode on loss of power for the rod drive systems; 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 the components provided to transfer the reactor’s thermal energy in normal operation from the boundaries of the reactor coolant system to the main condenser, and those systems and components provided for the return of condensate and feedwater 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 feedwater process lines;
— Auxiliary coolant systems;
— Relief and safety valves for steam generator pressure;
— Emergency feedwater pump;
— Stop, control, intercept and bypass valves for the turbine;
— Feedwater 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;
— Feedwater 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 to be conducted to demonstrate the operability of auxiliary and miscellaneous systems and, where appropriate, to verify redundancy and electrical independence. The following list is illustrative of the types of systems whose performance is demonstrated by testing:

- 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 leaktightness 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 the 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 within the plant, systems that may be used if the plant is required to be shut down from outside the control room, and communication systems required by the facility emergency plan.
- 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. Appropriate tests are to be made on the plant electrical systems including 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, and capability to transfer from on-site to off-site power sources.

(b) Vital busbar and associated AC power supplies: load tests that use either all the sources of power supplies to busbars or the minimum number.

(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, relay and logic devices, breakers, motor controllers, switchgear, transformers, transfer and trip devices, prohibiting and permissive interlocks, instrumentation and alarms, load shedding capabilities, capability of emergency and vital loads to start in the proper sequence and to operate under simulated accident conditions with both the normal (preferred) AC power sources and/or the emergency (standby) power 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 busbars using normal and emergency sources of power supplies to the busbar; 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 and steady state conditions; performance of auxiliary systems such as those used for starting, cooling, heating, ventilating, lubricating and fuelling, with the duration of the test being sufficient to ensure that equilibrium conditions are attained; logic, correct set points for trip devices and proper operation of initiating devices, prohibiting and permissive interlocks, redundancy and electrical independence.

Containment systems

A–10. In tests on the primary and secondary containment systems, account should be taken of the functional requirements during normal operation such as those for heating, ventilation and air conditioning, as well as isolation and integrity requirements under simulated accident conditions. Particular attention should be paid to:

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

Systems for disposal of radioactive waste

A–11. Tests on radioactive waste disposal 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 wastes, 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 required to demonstrate the operability of the equipment and components used to handle or cool irradiated fuel and to handle non-irradiated fuel in accordance with the design intent. These tests 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 (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 tests 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 (e.g. 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 personnel protection 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 particulate air filters and adsorption filters.

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 action and to monitor events. Instrumentation and control systems should be tested over the design operating range, and limiting malfunctions and failures should be tested by simulation. Any defensive measure to ensure the integrity of the instrumentation and control system also has to be tested (such as electromagnetic converter protection).

A–16. A listing of instrumentation parameters and equipment used for testing (some of this equipment may be tested in conjunction with the control system) should typically include the following:

- Pressurizer pressure and level;
- Reactor vessel level;
- Reactor coolant flow;
- Feedwater control;
- Automatic control of reactor temperature and power;
- Steam pressure in the secondary system;
- Detectors of reactor coolant system leaks;
- 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 startup instrumentation;
- Instrumentation and controls used for 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 the 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 features commonly provided:

(a) Emergency core cooling systems and essential auxiliary systems for equipment operability using normal and emergency power and cooling supplies, design pump runout conditions and injection at required flow rate and pressure; operability of overpressure protection for low pressure cooling systems.
(b) Autodepressurization system.
(c) Systems for post-accident removal of heat from the containment, spray systems and recirculation fans.
(d) Control system for combustible gases in the containment.
(e) Cold water injection interlocks.
(f) Emergency water supply system.
(g) Emergency feedwater 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 should also be conducted using the minimum number of operable components available with which these systems are designed to function. These include systems for heating, ventilation and air conditioning, cooling water and seal injection systems and protected compressed gas supplies. Protective devices, such as leaktight covers or housings provided to protect engineered safety features from flooding, or devices used to prevent the 'water hammer' effect and possible damage to fluid systems, are also included.

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 5.34–5.47 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 shut-off devices after the core is fully loaded; to the extent practicable, testing should demonstrate scram times for reactivity control rods at the extreme temperatures and flow ranges for the reactor coolant system.
— 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 of those across major components in the reactor coolant system; verification of the reactions of the piping to transient conditions (such as pumps starting and stopping) and to flows for all allowable combinations of pumps in operation; loss of flow tests conducted to measure flow coastdown.
— 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, 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:

- — 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 the 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 the rod insertion limits required to ensure an adequate shutdown margin, consistent with the assumptions for accidents (e.g. with the control rod of greatest reactivity worth failing to enter the core).
- — Measurements of absorber reactivity worth.
- — Determination of the absorber concentration at the initial allocation of criticality and reactivity.
- — Flux distribution measurement with normal rod patterns (this may be performed at a higher power, consistent with the sensitivity of in-core flux instrumentation).
- — Chemical and radiochemical measurements to demonstrate the design capability of the chemical control systems and of the installed analysis and alarm systems to maintain water quality within limits in the moderator, reactor coolant and secondary coolant system.
- — 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 the actual critical configuration with the predicted configuration.
- — Leak tests of the reactor coolant system.
- — Confirmation of the 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 the environmental parameters in the containment and to maintain important components in the containment within design limits, with the reactor coolant system at its rated temperature and with the minimum availability of ventilation system components for which the system is designed to operate.
— 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 and cleanup 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 the 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 defined 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 generator main breaker trip: with the method used for opening the generator output breakers (by simulating an automatic trip) selected such that the turbine generators will be subjected to the maximum credible overspeed condition they could encounter during plant operations.
— Tests with loss of off-site power (>10% of generator power output).
— Radiation surveys to determine the effectiveness of the shielding.
— On-power refuelling tests.
— Test of dropped rod: effectiveness of instrumentation in detecting a dropped rod and verification of associated automatic actions.
— Evaluation of flux asymmetry with a single rod assembly both fully 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.
— 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 the 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 feedwater 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 the 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, main, auxiliary and emergency feedwater control systems, hot well level control systems, steam pressure control systems and reactor coolant make-up and let-down control systems.
- Rod pattern exchange demonstration (at the maximum power that rod exchange will be permitted during operation).
- Determination of the dynamic response of the plant and the subsequent steady state of the plant for single and credible multiple trips of the reactor coolant pump or the circulator and/or failure of the flow control valves of the reactor coolant system.
- Trip-out of feedwater 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 and '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 condition 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.
- Demonstration of effectiveness of leak detection systems for reactor coolant, if not previously demonstrated.
- Operation of failed fuel detection systems in accordance with predictions.
- Shielding and penetration cooling systems: maintenance of temperatures of cooled components with the minimum design capability of cooling available.

— Performance of the auxiliary systems whose operable components have the minimum design capability for operation of the engineered safety features.
— Operation of processing, storage and release systems for gaseous and liquid radioactive wastes.
— 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; i.e. a direct electrical signal, not a secondary effect such as turbine overspeed).
— 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 piping and component movements, vibrations and expansions 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 feedwater heater(s) due to a credible single failure or operator error that results in the most severe case of a reduction in feedwater temperature.
— Tests of the load carrying capabilities of systems, components and cables.
— Test of shutdown from outside the control room.

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GLOSSARY

commissioning. The process during which nuclear power plant components and systems, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria. Commissioning may include both non-nuclear and nuclear tests.

licence. A legal document issued by the regulatory body granting authorization to perform specified activities related to the siting, design, construction, commissioning, operation and decommissioning of a nuclear power plant.

licensee. The holder of a current licence.

operating organization. An organization applying for authorization or authorized to operate a nuclear power plant and responsible for its safety.

operation. All activities performed to achieve the purpose for which a nuclear power plant was constructed. For a nuclear power plant, these include maintenance, refuelling, in-service inspection and other associated activities.

operational limits and conditions. A set of rules setting forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the regulatory body for safe operation of a nuclear power plant.

plant states.

operational states		**accident conditions**			
				beyond design basis accidents	
normal operation	anticipated operational occurrences	(a)	design basis accidents	(b)	severe accidents
				accident management	

(a) Accident conditions which are not explicitly considered design basis accidents but which are encompassed by them.
(b) Beyond design basis accidents without significant core degradation.

accident conditions. Deviations from normal operation more severe than anticipated operational occurrences, including design basis accidents and severe accidents.

accident management. The taking of a set of actions during the evolution of a beyond design basis accident:

— To prevent the escalation of the event into a severe accident,
— To mitigate the consequences of a severe accident,
— To achieve a long term safe stable state.

anticipated operational occurrence. An operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of a nuclear power plant but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions.

design basis accident. Accident conditions against which a nuclear power plant is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorized limits.

normal operation. Operation within specified operational limits and conditions.

operational states. States defined under normal operation and anticipated operational occurrences.

severe accident. Accident conditions more severe than a design basis accident and involving significant core degradation.

regulatory body. An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, radioactive waste and transport safety. The national competent authority for the regulation of radioactive material transport safety is included in this description.

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