

# IAEA SAFETY STANDARDS SERIES

## Commissioning for Nuclear Power Plants

### SAFETY GUIDE

No. NS-G-2.9



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# COMMISSIONING FOR NUCLEAR POWER PLANTS

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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.*

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# 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<sup>1</sup>.

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<sup>1</sup> 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 cleanliness, 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.