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No. NP-T-2.10

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COMMISSIONING GUIDELINES 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".

IAEA NUCLEAR ENERGY SERIES No. NP-T-2.10

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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

Commissioning is one of the key steps towards putting into service a new nuclear facility, or a new system, structure or component within an existing facility. The IAEA Safety Glossary (2007 edition) defines it as: "The process by means of which systems and components of facilities and activities, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria." Commissioning activities need to be planned for early in the design and procurement process, with careful consideration given to acceptance criteria and test methods, including those for tests performed in vendor factories.

Commissioning personnel play an important role in linking the construction phase of a project to the operating phase of the facility. They need to be knowledgeable about the regulations, codes, standards and procedures associated with both these phases of a nuclear facility's life, as well as the details of system design and testing, and commissioning methods. Therefore, planning for human resource development for commissioning staff is an important aspect of a nuclear power programme.

This publication is aimed at assisting in understanding and implementing the commissioning process for a new nuclear power plant or for upgrades or refurbishments of operating nuclear power plants. The work of all contributors to the drafting and review of this publication is greatly appreciated, and the IAEA wishes to thank the participants for their contributions. The IAEA officers responsible for this publication were J.H. Moore and K.S. Kang of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The IAEA Safety Glossary [1] defines commissioning as: “The process by means of which systems and components of facilities and activities, having been constructed, are made operational and verified to be in accordance with the design and to have met the required performance criteria”.

Commissioning is essential for safe and reliable nuclear power plant operation, and should be carefully planned and executed. Commissioning testing can place a facility into an abnormal state; therefore, safety precautions, including detailed planning, careful reviews and approvals, clear back out conditions (conditions that would cause the termination of a test, maintenance activity, or other work in order to avoid an unsafe condition being met), and emergency response capabilities, need to be in place for field activities. Commissioning results demonstrate that design requirements, design intents and safety requirements, as stated in system specifications, safety analysis reports and licence conditions, have been met for the nuclear facility as constructed. Commissioning data will be used to confirm design parameters and initial system and equipment characteristics, and will provide source values for future periodic tests.

Nuclear power plant (NPP) construction schedules, from the first pouring of structural concrete to grid connection, can range from less than five years to longer than twenty years. Achieving a short and predictable construction duration is critical to the financial success of any new power plant project. Commissioning duration can, however, be difficult to predict owing to many factors, such as the risk of unexpected test results that may require rework.

Considering the fact that only few plants have been commissioned recently, especially in traditional markets, a sufficient number of experienced commissioning personnel may not be available in a jurisdiction when NPP commissioning activities actually need to occur. If several plants are commissioned simultaneously around the world, a shortfall of knowledge and of experienced personnel may very well cause bottlenecks and schedule delays.

Taking into account this possibility, the IAEA initiated work to collect from Member States currently involved in commissioning activities the information and experience available today on the conduct of nuclear facility commissioning and startup. Figure 1 gives an overview of NPPs in the world as of December 2017.

This publication is based on principles and methods applied and recognized by operating organizations and regulators in different countries, and complements IAEA Safety Standards Series No. SSG-28, Commissioning for Nuclear Power Plants [2].

1.2. OBJECTIVES AND SCOPE

This publication addresses issues related to NPP commissioning and its interfaces with construction and operations, and describes good industry practices that meet safety and quality standards during commissioning that allow commissioning to proceed in an efficient manner. It addresses:

— The definition of commissioning and of a commissioning programme, and the main objectives of commissioning;
— General arrangements and sequence of tests;
— Key aspects and principles related to the management, organization and implementation of commissioning;
— Operating experience feedback and lessons learned on potential plant commissioning organization and resources, on commissioning schedule management and on commissioning implementation management.

In particular, this publication allows newcomer countries to gain insight into the key steps in the commissioning process, the important role of the owner/operator and human resource considerations.

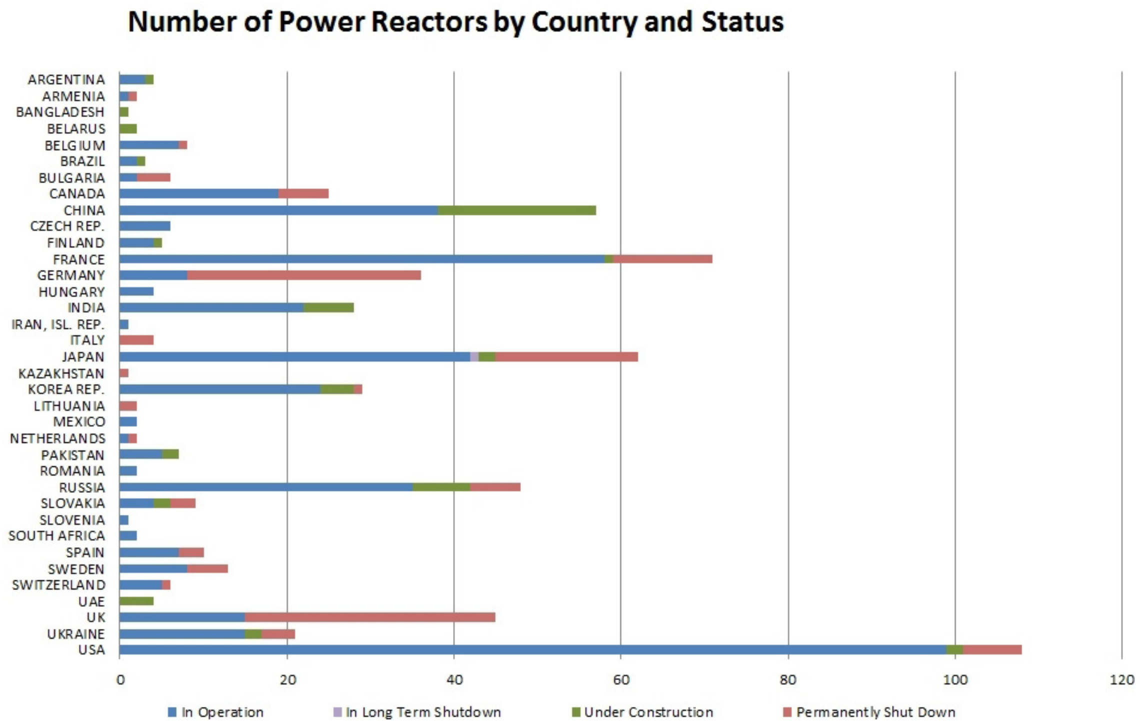

FIG. 1. Power reactors by status worldwide (as of December 2017). Source: IAEA Power Reactor Information System.

1.3. USERS

The following organizations are foreseen as users of this guide:

— Owner/operators (responsible for nuclear facilities as a whole and for oversight of the commissioning process);
— Main contractors (responsible for installation activities and with varying roles in the commissioning process);
— Architect–engineers (providing support to the owner/operator or main contactor as defined in contracts);
— Consultants (providing support to the owner/operator, main contractor or architect–engineers as defined in contracts);
— Subcontractors (providing support to the owner/operator, main contractor, architect–engineers or other consultants as defined in contracts);
— Regulatory bodies (national and local regulators responsible for the regulatory framework surrounding facility construction, commissioning, operation and decommissioning);
— Equipment vendors/suppliers (responsible for providing material and equipment for NPP facilities and typically providing support for the commissioning process for their supplied equipment).

1.4. STRUCTURE

Section 2 of this publication describes the basics of commissioning, and Section 3 describes management requirements related to commissioning. Section 4 details the commissioning process for NPPs, including the steps involved and the documentation required. Section 5 describes human resource issues related to commissioning programmes, and typical organizational models in use in various Member States. Section 6 covers safety and provides experience and lessons learned related to NPP commissioning.

Appendices present examples and practical details on specific items. These include stages and content of commissioning tests; typical commissioning organizational models; and typical examples of commissioning related checklists, commissioning activities and arrangements for sharing responsibilities between commissioning and operating organizations.

2. COMMISSIONING BASICS

2.1. WHAT IS COMMISSIONING?

In its simplest form, commissioning is the confirmation that an installed system functions as per its requirements. The basic steps involved can be illustrated through the use of a model of a simple system such as that of lights installed in a room with switches outside of it (Fig. 2).

In this example, light switches are outside of a room containing lamps that they are designed to control. An individual who is responsible for system commissioning finds the light switch SW1 in the ‘ON’ position, enters the room and sees Lamp 1 illuminated. The individual cannot assume via these checks that the system can be confirmed functional and commissioned for a number of reasons. Lamp 1 may in fact have been connected to a different power supply and be illuminated from that supply (i.e. not powered through the circuit controlled by SW1). The light switch SW1 itself has not been tested and might not be functioning correctly. It may be stuck or shorted in the ‘ON’ position with no possibility to turn the light off. Independent electrical circuits including other switches or components (e.g. SW2, Lamp 2, Lamp 3 or other circuits entirely) might have been wrongly interconnected to the circuit which was to control Lamp 1. Additionally, light switch SW1 that was meant to only operate Lamp 1 may be incorrectly connected to and unintentionally controlling other circuits. The wrong size light bulb may have been installed in Lamp 1 and it may be overloading its electrical supply or heating the room excessively.

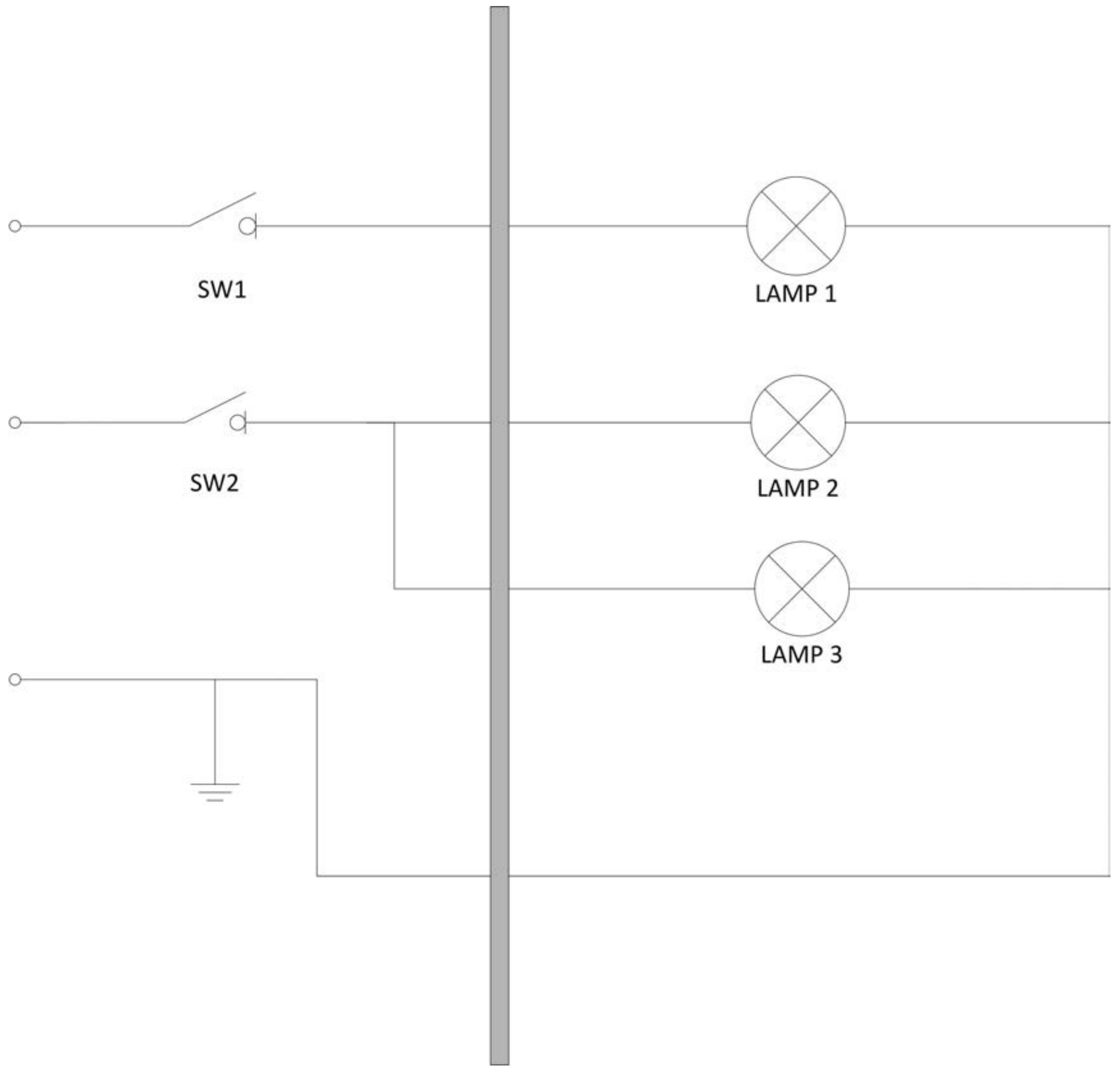

FIG. 2. Example of commissioning basics — commissioning lighting circuits.

With this in mind, how can we reasonably ensure that the circuit for SW1 and Lamp 1 meets all of its design requirements? A robust set of commissioning steps will be needed and may have to include the following:

- Even before starting commissioning, circuit installers provide evidence that wiring connections have been checked against design drawings, and commissioning staff ensure that this evidence has been provided.
- Commissioning staff perform a series of tests such as:
  - Confirm initial test conditions:
    - Check that light switch SW1 is in ‘off’ position.
    - Check that Lamp 1 is extinguished (is ‘off’).
    - Measure current drawn by circuit at light switch SW1 to ensure it is zero and record the reading below:
      - ___________ amperes (A) (expected result 0 A).
  - Set light switch SW1 to ‘on’ position and:
    - Confirm that Lamp 1 illuminates (turns ‘on’).
    - Measure current drawn by circuit at light switch SW1 and record its value below:
      - ___________ A (expected result 0.5 A ± 5%).
    - Confirm that no anomalies occur with other lights in the building coincidentally with this commissioning sequence (e.g. no other lamps in the building, such as Lamp 2 or Lamp 3, unexpectedly illuminate or extinguish).
  - Set light switch SW1 to ‘off’ position and:
    - Confirm that Lamp 1 extinguishes.
    - Measure current drawn by circuit at light switch SW1 and record its value below:
      - ___________ A (expected result 0 A).
    - Confirm that no anomalies occur in other circuits or with other lights in the building coincidentally with this commissioning sequence (no other lamps in the building, such as Lamp 2 or Lamp 3, unexpectedly illuminate or extinguish).
  - Forward all commissioning results to the design engineer for review and acceptance.

Similar steps would be used to commission the circuits for SW2 and Lamp 2 and Lamp 3.

The above example illustrates the basic commissioning process of (a) confirming an initial state, (b) initiating a change and watching for a correct response, and (c) reversing the change and watching for the reverse response or an otherwise correct different response.

In an NPP environment, with thousands of components installed, commissioning is a complicated endeavour that requires highly trained staff and detailed test programmes and procedures. Such a process will provide the means to:

- Verify that the plant is built as designed and that structures, systems and components (SSCs) fulfil design operational and safety objectives through corresponding acceptance criteria;
- Evaluate potential discrepancies against design parameters and determine tolerances for initiating corrective actions;
- Determine the level of installation adequacy (the quality and accuracy of the installation where this can be detected via commissioning);
- Validate operating procedures and testing manuals as far as is reasonably possible;
- Prove testing and inspection practices for commissioning and future operating organization activities;
- Ensure records are available for use by operating organization staff for future activities.

2.2. TIMING OF COMMISSIONING

Planning for commissioning begins early in a project. Activities related to commissioning occur during project design, procurement, construction, the formal commissioning phase and plant startup. For new NPPs, a commissioning programme continues through fuel loading, first criticality and power ascension, and it generally ends with plant performance tests and a trial operation run. The trial run is carried out at full power to demonstrate unit operating capability and performance.

Following plant startup and throughout a facility's life, refurbishments or modifications to plant systems are made that will require their own commissioning steps.

Commissioning covers, to the extent practical, all plant conditions considered in the safety analysis report and in licence conditions. Testing is performed under conditions as close as possible to design conditions.

Commissioning programmes cover all activities performed on SSCs to confirm their function in accordance with design intent. They encompass testing of components, parts of systems, complete systems and the integrated plant. Commissioning can consider both off-site tests performed before installation and on-site tests. Off-site tests are called factory acceptance tests (FATs) and are performed at a manufacturer's factory or in other off-site test facilities. On-site tests include checks and tests of installed components and systems during construction, commissioning and plant startup. On-site tests called site acceptance tests (SATs) consist of component or system tests done on site following delivery, and have to be completed before a supplier's product can be fully accepted. Other related testing can include proof of concept tests or mock-up tests that are not strictly part of commissioning but can improve confidence that certain newly developed equipment will be able to be successfully commissioned later. An example of linkage between FAT and site testing is shown in Fig. 3.

Strong linkages between the commissioning, design and procurement organizations are needed to ensure complete and correct commissioning. Design and procurement begin well before on-site commissioning, and the related organizations are heavily involved in specifying acceptance criteria for equipment, components and services that are purchased from suppliers. Suppliers perform or are involved with factory and site acceptance testing according to inspection and test plans that are typically approved by design personnel. In order to seamlessly specify appropriate commissioning activities, commissioning personnel need to understand the details and the results of the tests that have been performed as part of the inspection and test plans. IAEA Nuclear Energy Series No. NP-T-3.21 [3] covers establishing purchasing requirements, inspection and test plans, and FAT and SAT testing in more detail.

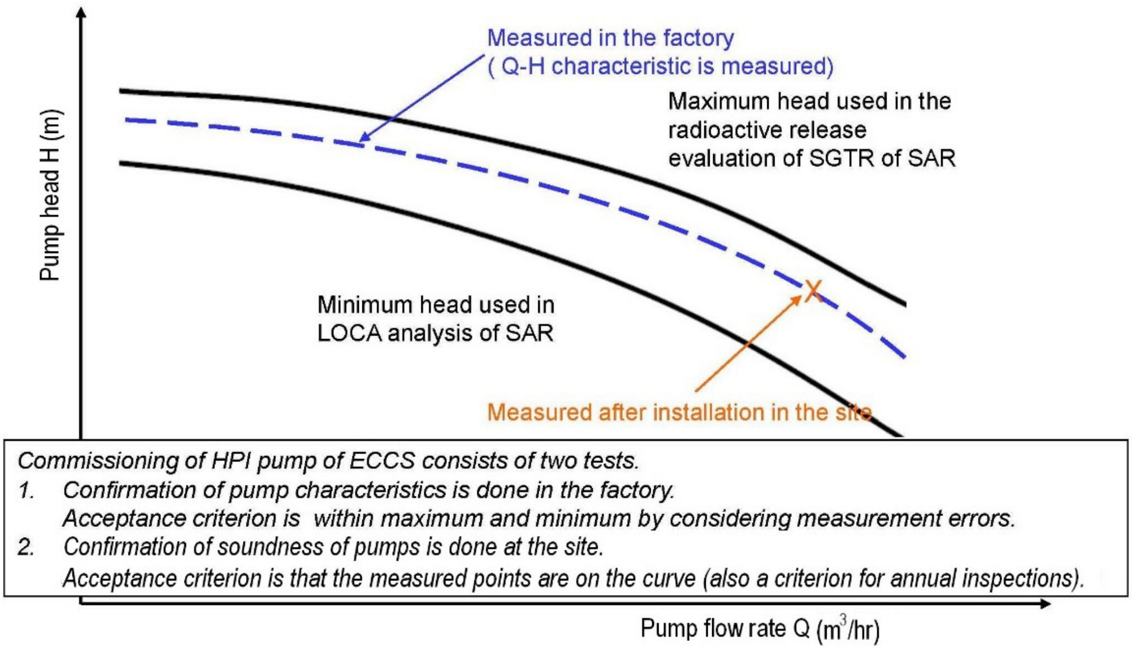

FIG. 3. Relationship between FAT and site commissioning test for a pump. ECCS — emergency core cooling system; H — head; HPI — high pressure injection; LOCA — loss of coolant accident; Q — flow; SAR — safety analysis report; SGTR — steam generator tube rupture (courtesy of S. Fujii).

2.3. COMMISSIONING RESPONSIBILITIES

On-site commissioning is typically jointly implemented by the commissioning and operating organizations. Clear responsibilities need to be assigned for planning and implementation of tests during the commissioning stage. During commissioning, the construction and commissioning organizations will initiate practices and processes that establish life cycle precedents for the operational phase. These precedents apply to many areas, but the owner/operator should be especially sensitive to inspection, testing and as-built data collection activities that verify as-built conformance of SSCs to the design basis and safety requirements. Variations from design intent found in these checks are assessed, corrected and referred to the operating organization so that any effect on installation can be addressed.

2.4. LINK TO DESIGN AND SAFETY REQUIREMENTS

Commissioning is designed to prove that installed systems meet all design and safety requirements. Design and safety requirements are translated into a set of commissioning specifications and objectives, with defined acceptance criteria. These specifications and objectives form the basis for specific test instructions and commissioning procedures to be used in the plant by commissioning personnel. Results of these tests are recorded and submitted to the competent persons (typically in the design organization) for evaluation. If the results are acceptable, the competent persons confirm that the installation meets the written requirements for the system. Figure 4 illustrates these links.

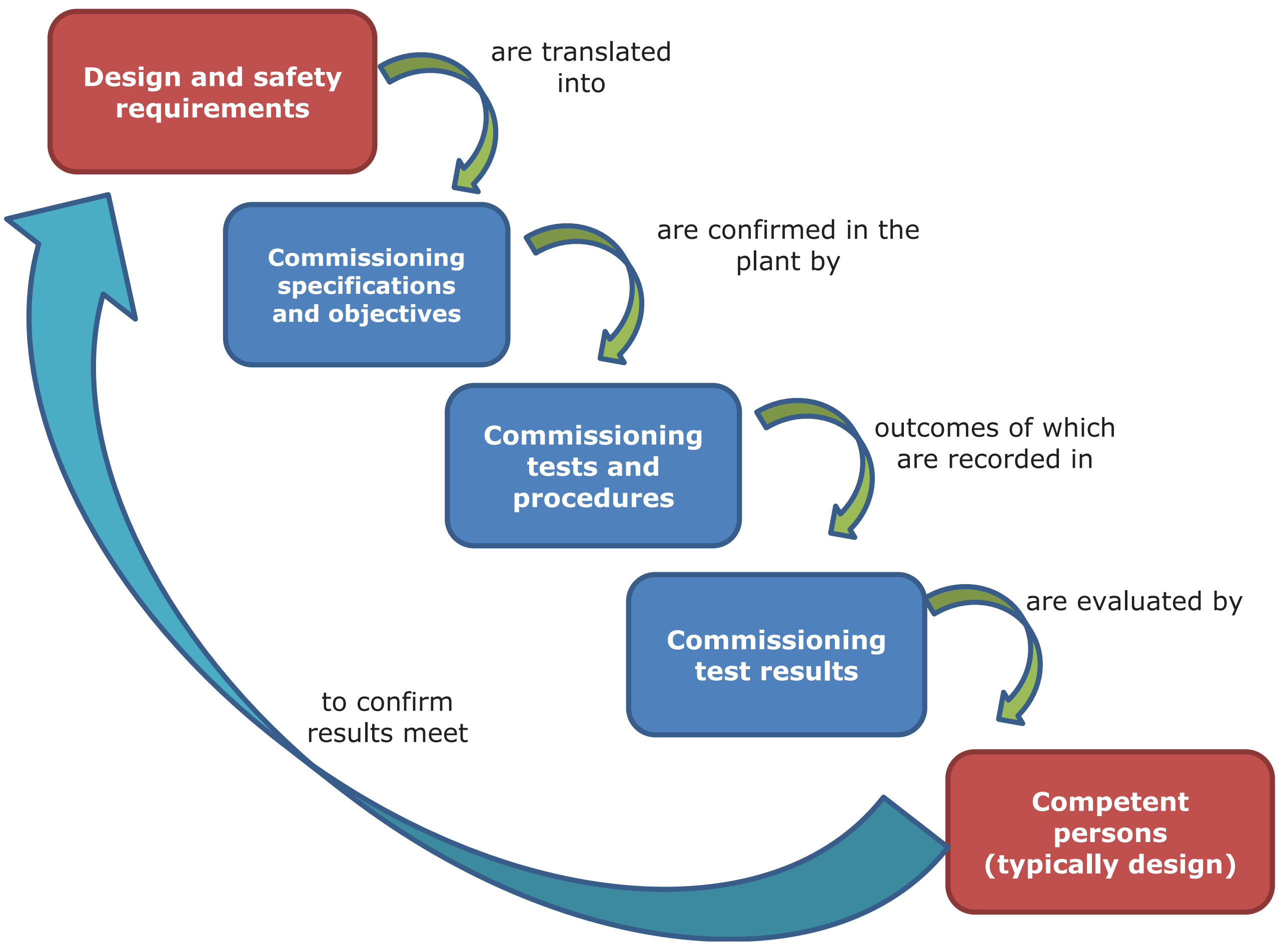

FIG. 4. Links between design and safety requirements and commissioning activities.

3. MANAGEMENT SYSTEMS FOR COMMISSIONING

3.1. INTEGRATED MANAGEMENT SYSTEM REQUIREMENTS

Commissioning is fundamental to NPP safety and accident prevention. Defence in depth is provided by an effective management system. Such a system needs to include a strong management commitment to safety and a strong safety and security culture. This includes ensuring high quality commissioning.

A key safety fundamental applying to all NPPs is that “The person or organization responsible for any facility or activity that gives rise to radiation risks … has the prime responsibility for safety” (para. 3.3 of IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [4]). This means that when an NPP owner purchases or delegates services that can affect nuclear safety, the owner nevertheless retains responsibility for that safety and needs to have processes in place to maintain safety under all conditions. This prime responsibility for safety thus cannot be transferred or delegated to NPP vendors, suppliers, constructors, or outside technical support organizations during commissioning or any other stage.

A management system is a set of interrelated or interacting elements for establishing policies and objectives and enabling objectives to be achieved in an efficient and effective way. Such systems have evolved over time from pure quality control systems (e.g. simple checks such as inspections and tests) to quality assurance and quality management systems (such as those described in International Organization for Standardization (ISO) standards), and more recently to integrated management system approaches like that described in IAEA Safety Standards Series Nos GSR Part 2, Leadership and Management for Safety [5], GS-G-3.1, Application of the Management System for Facilities and Activities [6], and GS-G-3.5, The Management System for Nuclear Installations [7]. An integrated management system provides a single framework for the arrangements and processes necessary to address all the goals of the organization. These goals include safety, health, environmental, security, quality and economic elements, and other considerations such as social responsibility. A key advantage of the integrated management system approach (compared with quality management systems such as ISO standards) is that it incorporates safety.

NPPs are required by national regulators to have a documented management system that governs the performance of their work. Specific requirements can vary, however most regulations are aligned with GSR Part 2 [5] (which comprises the high level requirements), GS-G-3.1 [6] (which contains specific guidance for operating nuclear facilities and related activities) and GS-G-3.5 [7] (which provides even more specific guidance for NPPs).

IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation [8], covers commissioning and operation up to the removal of nuclear fuel from the plant, and SSG-28 [2] covers commissioning in detail. SSG-28 supersedes IAEA Safety Standards Series No. NS-G-2.9[1].

Paragraphs 3.1 to 3.12 of SSG-28 cover commissioning management systems, and are consistent with the requirements in GSR Part 2 [5], GS-G-3.1 [6] and GS-G-3.5 [7]. Additional details are provided regarding what should be addressed in the commissioning management system, including the timing of each activity, grading of commissioning requirements, documentation, objectives, application of safety culture, procedures and oversight. The main objective of the management system during commissioning is to ensure the NPP meets all requirements specified by regulators, design documents, safety analysis reports, and operating limits and conditions, and the administrative requirements of the licensee.

Sections of IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations [9], deal with the turnover to the commissioning organization following construction.

3.2. NATIONAL AND INTERNATIONAL COMMISSIONING STANDARDS

NPP commissioning is conducted according to the applicable national or international standards. Such standards are typically based on a multi-level hierarchical legislative system. An example of such a system is shown in Fig. 5.

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-2.9, IAEA, Vienna (2003).

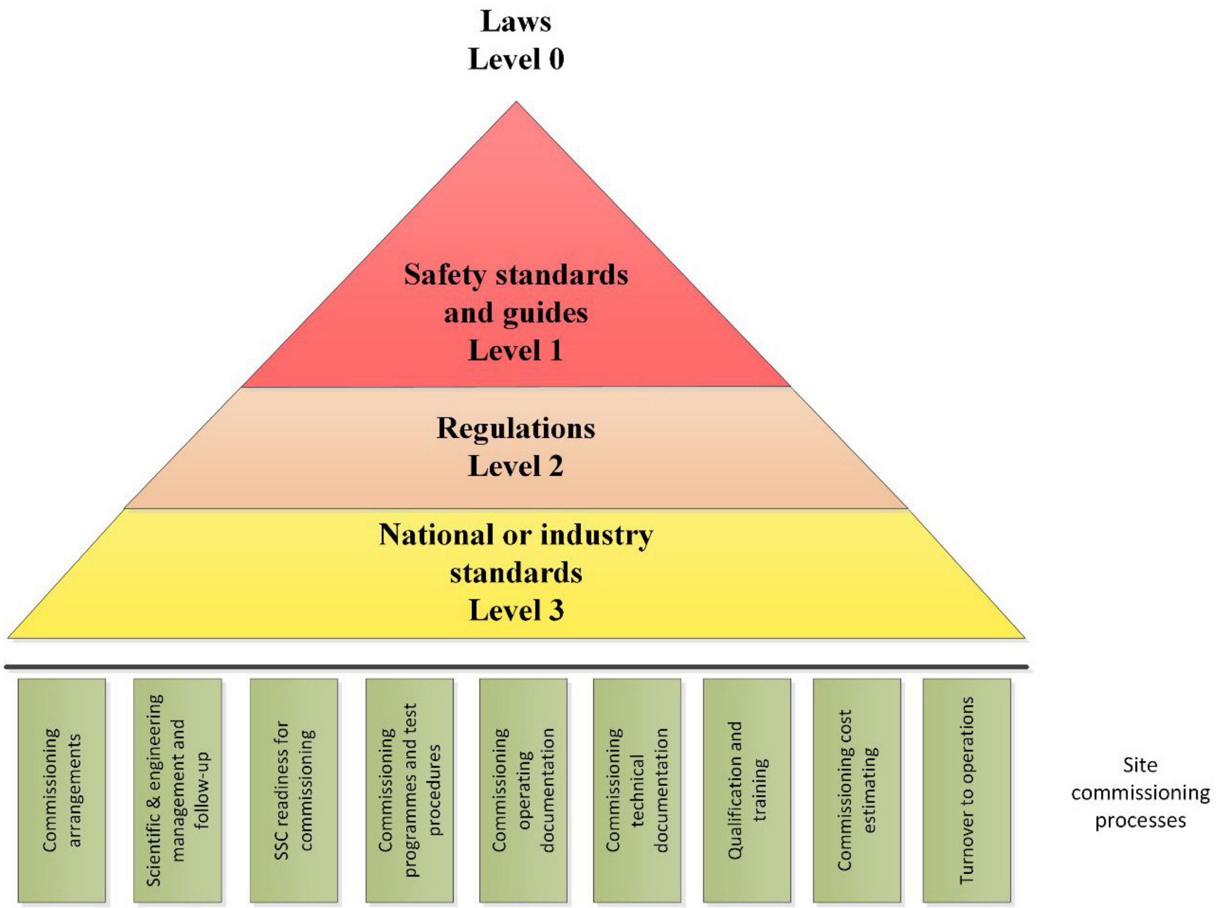

FIG. 5. Example of multi-level hierarchical legislative system for commissioning.

Level 0 comprises national or international laws related to the exploitation of nuclear energy.

Level 1 consists of national or international safety standards or guides related to nuclear, radiological, industrial, and fire safety and environmental protection at different stages of the NPP life cycle, including the commissioning period. These include the IAEA safety standards described in Section 3.1.

Level 2 contains national (or international) regulations on construction, commissioning, operation, testing and inspection, emergency preparedness and quality assurance.

Level 3 includes national or industry standards related to different aspects of commissioning.

Table 1 lists examples of Level 2 and 3 documents from various countries and international organizations that are applicable to commissioning.

The number and content of commissioning standards is determined by the structure, content and requirements of commissioning regulations as well as the power plant technology. For example, historical commissioning documents related to water cooled, water moderated power reactors typically consisted of approximately 44 industry standards, 143 reference test procedures and 6 commissioning price lists (which were cost estimation documents for commissioning tasks during the Soviet era).

3.3. DOCUMENTING THE MANAGEMENT SYSTEM

Management systems for general NPP activities are established by the operating organization. Other organizations participating in construction and commissioning establish and implement management systems for their related activities that are based on general requirements established for the NPP. The commissioning organization in particular develops administrative and commissioning management processes for commissioning activities in accordance with national and international standards (as described in Sections 3.1 and 3.2). The number and the scope of procedures will depend on the applicable standards. As stated in para. 6.1 of SSR-2/2 (Rev. 1): “Commissioning stages, test objectives and acceptance criteria shall be specified in such a way that the programme is auditable” [8].

On-site commissioning activities are driven by a comprehensive documented commissioning plan and programme. This brings the plant to safe commercial operation in compliance with international safety requirements, national laws, safety guides, regulations and standards, and with consideration of industrial regulations and quality standards. Establishing specific management system and documentation requirements within this commissioning programme is a key activity that needs to take place well prior to the start of commissioning. According to para. 5.1 of SSG-28: “The structure, content, extent and control of commissioning documents should … be specified in the management system of the operating organization” [2].

Commissioning documentation covers organizational, administrative, safety, environmental and technical aspects of commissioning. These include organizational structures and responsibilities, organization and systems for commissioning management and control, and administrative procedures for commissioning activities and reporting (responsibilities for turnovers/handover, etc.).

Technical commissioning documentation covers technical aspects, describing for example the overall plant commissioning programme, commissioning programme phases and sequences, the commissioning programme for each system, test sequences, test procedures, limits, constraints and acceptance criteria. It may include such items as commissioning reports, plant operation documents (e.g. operating instructions, maintenance instructions, routine test procedures), commissioning input data and support documents (e.g. commissioning standards, design documentation, calibration setpoints).

The specific structure and content of this documentation is discussed in Section 4.2.2 (Section 4.2 deals with preparations for commissioning).

3.4. KNOWLEDGEABLE CUSTOMER ROLE

NPP owners and regulators often use the concept of the ‘knowledgeable customer’, sometimes referred to as ‘intelligent customer’ or ‘smart buyer’, when developing their management system for dealing with service or major equipment suppliers. IAEA Safety Standards Series No. GSG-4, Use of External Experts by the Regulatory Body [10], defines this as “the capability of the organization to have a clear understanding and knowledge of the product or service being supplied.” The concept relates mainly to a capability required of organizations when procuring support from contractors, technical support organizations or other external experts. It allows for discrete, ‘hands-on’ oversight of critical activities where outcomes may not be well-defined. IAEA Nuclear Energy Series No. NP-T-3.21 [3] on procurement describes this role in more detail. Commissioning related services that may be contracted include design (NPP supplier and/or owner’s architecture–engineering firm), installation support, calibration services, on-site support from original equipment supplier representatives, inspection services and administrative support.

A key role of the knowledgeable customer is to exercise guidance and oversight for the services being provided. This involves ensuring that service or major equipment suppliers carry out and use formal assessments, provide their own internal managerial oversight, and have and use continuous improvement processes for the services supplied. Regular contact and review meetings with key suppliers to share observations surrounding performance are helpful.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES

Country/ organization	National regulation, code or standard related to commissioning	Comment
Canada	N286-12, Management System Requirements for Nuclear Facilities [11]	Replaces N286.4, Commissioning Quality Assurance for Nuclear Power Plants [12] for commissioning and other aspects of NPPs. N286-12 has specific clauses regarding control of commissioning. Commissioning of SSCs includes prerequisites, control of commissioning activities, completion assurance, documentation, and review of results.
	REGDOC-2.3.1, Conduct of Licensed Activities: Commissioning of Reactor Facilities [13]	Sets out requirements and guidance for commissioning of nuclear reactor facilities (NPPs, small reactors and research reactors). Sections cover commissioning programmes, management and organization, commissioning tests, regulatory hold points and recommended tests for specific commissioning phases.
	Guidelines for Pre-start Health and Safety Reviews: How to Apply Section 7 of the Regulation for Industrial Establishments (Ontario) [14]	Example of typical industrial safety regulations surrounding equipment and process startup reviews.
China	HAD003/09, Quality Assurance During Commissioning and Operation of of Nuclear Power Plants [15]	
Finland	YVL 1.4, Management Systems for Nuclear Facilities [16]	Guidance to licensees responsible for ensuring compliance with regulatory requirements and for product procurement having a bearing on nuclear and radiation safety.
	YVL 2.5, The Commissioning of a Nuclear Power Plant [17]	Describes commissioning objectives, organization and quality management systems. Provides guidance for commissioning and test plans and requirements for testing programmes, and specifies the role and responsibilities of the regulator.
France	AFCEN RCC-E, Design and Construction Rules for Electrical and I&C Systems and Equipment [18]	Provides design and construction rules for electrical components and software in the nuclear island whose failure could threaten personnel or nuclear safety. It can be used as a reference in contracts between customers and suppliers. It covers commissioning testing. Volume VII lists various inspection and test methods and acceptance criteria for electrical equipment. Appendix Z.5000 lists management system requirements in accordance with GSR Part 2 [5].
	Decision No. 2013-DC-0347 by the French Nuclear Safety Authority of 7 May 2013 setting out requirements to be met by Électricité de France at Flamanville nuclear site for the Flamanville 3 reactor (INB No. 167) commissioning tests [19]	Covers regulatory commissioning requirements for Flamanville 3, including inspections and tests, safety policy and management, and required reports.
	AFCEN RCC-M RPP No. 1, Nuclear Management System [20]	Quality assurance system utilized for French NPPs and referenced in some other jurisdictions. Major sections cover the content of the management system, responsibilities, management of resources, processes and corrective actions.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
India	AERB/SG/O-4, Commissioning Procedures for Pressurised Heavy Water Reactor Based Nuclear Power Plants [21]	Covers all phases of an NPP commissioning programme, including test procedures, organization, responsibilities, auditing, interfaces with construction and operations, deviations, and documentation requirements.
International Code Council	ICC G4-2012, Guideline for Commissioning [22]	Provides guidance for a code official or regulator to use in order to competently oversee building commissioning and enforce applicable codes and regulations, with either in-house or supervised third party staff.
International Electrotechnical Commission (IEC)	IEC 62381:2012, Automation Systems in the Process Industry — Factory Acceptance Test (FAT), Site Acceptance Test (SAT), and Site Integration Test (SIT) [23]	Defines procedures and specifications for FAT, SAT and SIT. These tests are carried out to prove that an automation system is in accordance with its specification.
International Organization for Standardization (ISO)	ISO 9001:2008, Quality Management Systems: Requirements [24]	See Ref. [25] for comparison to GS-R-3[a].
Russian Federation	NP-082-07, Rules of Nuclear Safety NPP Reactors [26]	Section 3 covers ensuring nuclear safety during NPP unit commissioning.
	OPB-88/97 NP-001-97 (PNAE G-01-011-97), General Safety Regulations for Nuclear Thermal Power Plants [27]	Provides general regulations on ensuring safety of NPPs. Section 5.2 covers commissioning (requires operating organization to develop and implement the commissioning programme, define acceptance criteria in design, separate unit under commissioning from operating units, incorporate a regulatory hold point prior to commissioning, adjust operating manuals based on commissioning data, and other items).
	STF EO 0009-03 (with Amendment 1 2014), Water Chemistry of the Primary Loop During VVER-1000 Startup [28]	Establishes requirements for quality of primary loop coolant and aqueous solution of safety systems and reactor island auxiliary systems, and for monitoring of water chemistry during VVER-1000 startup.
	STO 1.1.1.03.003.0759-2008, Preparedness of Systems, Equipment and Facilities of VVER-1000 NPPs (Project V-320) for Commissioning: Technical Requirements [29]	Establishes general technical requirements for construction, installation and technological readiness for systems, equipment and facilities for VVER-1000 NPPs (project V-320) for the commissioning stage.
	STO 1.1.1.03.003.0879-2012, Commissioning of Blocks of Nuclear Power Stations with Water-water Power Reactors: Procedure of Performance and Acceptance of Start-up and Adjustment Works on Technological Systems and Equipment [30]	Sets out requirements for conduct and acceptance of commissioning of technological equipment and systems of with water cooled, water moderated NPPs.
	STO 1.1.1.03.003.0880-2013, Commissioning of Blocks of Nuclear Power Stations with Water-water Power Reactors: Volume and Sequence of Start-up and Adjustment Works — General Provisions [31]	Specifies general requirements for the scope and sequence of commissioning of water cooled, water moderated NPPs.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
	STO 1.1.1.03.003.0881-2012, Commissioning of Blocks of Nuclear Power Stations with Water-water Power Reactors: Terms and Definitions [32]	Sets out basic terms and definitions for commissioning of NPP units with water cooled, water moderated power reactors.
	STO 1.1.1.03.003.0906-2013, Commissioning of NPPs Equipped with Water-cooled Water-moderated Power-generating Reactors: Procedure for Carrying out and Acceptance of Electrical Equipment Commissioning [33]	Sets out requirements for conduct and acceptance of commissioning of electrical equipment and systems of water cooled, water moderated NPPs.
	STO 1.1.1.03.003.0907-2012, Commissioning of NPP Units: Report Documentation [34]	Establishes requirements for composition and forms of reporting documentation prepared in the process of commissioning NPP units.
	STO 1.1.1.03.003.0914-2013, Conduct and Acceptance of Commissioning of I&C Process Systems (Rev. 1) [35]	Sets out requirements for conduct and acceptance of instrumentation and control (I&C) process system commissioning for water cooled, water moderated NPPs, taking into consideration modification and operational safety aspects. Covers commissioning of I&C process systems during the phase in which they are put into operation according to Russian National Standard (GOST) 34.601-90.
	STO 1.1.1.03.003.0916-2013, Procedures for Commissioning of NPP Units [36]	Establishes procedures for commissioning of NPPs following construction. Specifies requirements for the composition, main responsibilities and functions of the acceptance commission, working committee and subcommittees.
	STO 1.1.1.03.004.0979-2014, Water Chemistry of the Secondary Loop During Commissioning of VVER NPPs (Design AES-2006): Water Chemistry Monitoring [37]	Establishes requirements for the quality of the aqueous solution of the second circuit, and aqueous solution of auxiliary systems, as well as requirements for water chemistry during water cooled, water moderated power reactor (AES-2006) startup and operation.
	STO1.1.1.03.004.0980-2014 (as Amended 2015), Water Chemistry of the Primary Circuit During Commissioning of VVER NPPs (Design AES-2006): Quality Standards for the Coolant and Tools for Their Support [38]	Establishes requirements for the quality of the primary coolant, aqueous solution of safety systems and auxiliary systems of the reactor compartment, as well as the requirements for water chemistry monitoring during water cooled, water moderated power reactor (AES-2006) startup and operation.
	RD 95 10346-88, Regulation on the Order of Organization and Implementation of Commissioning, Supervision and Maintenance Services at Nuclear Power Plants for Equipment for Monitoring and Protecting Nuclear Reactors and Nuclear Power Plants [39]	Sets out requirements on preparation and conduct of commissioning, designer supervision and maintenance service at NPPs for commissioning and maintenance of reactor control and protective systems, and software for in-core instrumentation systems.
	RD EE 1.1.2.28.760-2015 (with Amendments 1 2016, 2 2017), Integrated Measures to Ensure the Operational Readiness of New Power Units of Nuclear Power Plants: General Requirements [40]	Establishes general requirements for the development plan, content and implementation conditions for comprehensive measures for ensuring the operational readiness of new NPPs.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
	RD EE 1.1.2.01.0869-2015, Regulation on Management of Non-conformities During Commissioning of New Power Units of NPP [41]	Establishes procedures for nonconformity control in the process of NPP commissioning. Determines responsibility and interaction procedures between organizations involved in NPP unit commissioning when correcting non-conformities.
	RD EO 1.1.2.99.0963-2014, Commissioning of Nuclear Power Plant Units: Quality Control of Commissioning at Nuclear Power Plants of OJSC Concern Rosenergoatom NPPs [42]	Sets out general requirements for organization of quality control for commissioning of NPPs for all types of reactors.
	MT 1.2.2.04.0069-2012, Methods for Monitoring the Safety Related Dynamic Characteristics of NPP Systems and Components [43]	Establishes methods for determining dynamic characteristics of NPP systems and components important to safety. Establishes requirements for technical measurement tools, procedures, mathematical models and software tools.
	PNAE G-7-008-89, Rules for Arrangement and Safe Operation of Equipment and Piping of Nuclear Power Installations [44]	Section 8.3 covers permissions needed from the regulator to begin commissioning of nuclear piping systems. Section 7 covers pre-commissioning inspections.
	OST 34-37-788-85, Hook Up and Commissioning Works at Nuclear Power Plants (NPP) with Water-to-Water Power Reactors: Requirements to Personnel — General Requirements [45]	Sets out general requirements for commissioning personnel. Developed based on Safety Series No. 50-C-O[b].
	OST 34-37-796-85, Hook Up and Commissioning Works at Nuclear Power Plants (NPP) with Water-to-Water Power Reactors: Volume and Sequence of Hook Up and Commissioning Work — First Criticality [46]	Sets out the scope of commissioning, test conditions and final acceptance criteria for the first criticality phase. Developed in accordance with Russian Nuclear Safety Regulation PBYa-04-74 and Safety Series No. 50-SG-04[c].
	OST 34-37-797-85, Hook Up and Commissioning Works at Nuclear Power Plants (NPP) with Water-to-Water Power Reactors: Volume and Sequence of Hook Up and Commissioning Works — Power Start-up and Unit Designed Capacity Adaptation [47]	Sets out the scope of commissioning, test conditions and final acceptance criteria for the power ascension phase. Developed in accordance with Russian Nuclear Safety Regulation PBYa-04-74 and Safety Series No. 50-SG-04[c].
	OST 34-37-798-85, Hook Up and Commissioning Works at Nuclear Power Plants (NPP) with Water-to-Water Power Reactors: General Specifications for Equipment and System Testing [48]	Sets out general technical requirements for equipment and system tests during commissioning. Developed in accordance with Russian Basic Safety Rules for Nuclear Plants (OPB-82) and Safety Series No. 50-C-O[b].
	OST 34-37-799-85, Hook Up and Commissioning Works for Nuclear Power Plants with Water-to-Water Power Reactors: Technical Documentation — General Requirements [49]	Sets out the requirements for technical commissioning documentation and documentation management for water cooled, water moderated NPPs. Developed based on Safety Series No. 50-C-O[b].
	OST 34-37-809-85, Hook Up and Commissioning Works for Nuclear Power Plants with Water-to-Water Power Reactors: Report Documentation — General Provisions [50]	Sets out the goals and purpose, range of influence and applicability of a set of industry standards related to commissioning report documentation. Developed based on Safety Series No. 50-C-O[b].

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
United Arab Emirates	FANR-REG-16, Draft Regulation on Operational Safety Including Commissioning [51]	Article 24 covers licensee requirements surrounding the commissioning programme, including the requirement to confirm that the programme demonstrates that the facility meets the requirements of the safety analysis report and design intent, and that operating and maintenance procedures are validated to the extent practicable.
United Kingdom	Licence Condition Handbook [52]	Licence Condition 21 covers commissioning and requires the licensee to prepare and implement adequate arrangements for commissioning of any plant or process which may affect safety. Specifies interfaces with regulator.
	NS-TAST-GD-028, Control and Instrumentation Aspects of Nuclear Plant Commissioning [53]	Guide to assist Office of Nuclear Regulation I&C specialist inspectors in judging the adequacy of plant commissioning arrangements with respect to nuclear safety.
	NS-TAST-GD-049, Licensee Core and Intelligent Customer Capabilities [54]	Helps regulatory inspectors assess suitability of approaches a licensee may take to maintain in-house expertise to provide continuing control and oversight of nuclear safety, including the oversight of contractors whose work has the potential to impact nuclear safety.
	Chartered Institution of Building Services Engineers Commissioning Codes: Code A: Air Distribution Systems [55] Code B: Boilers [56] Code C: Automatic Controls [57] Code L: Lighting [58] Code M: Commissioning Management [59] Code R: Refrigerating Systems [60] Code W: Water Distribution Systems [61]	Deal with the steps that must be completed in order to commission a typical commercial building, including heating, ventilation and air conditioning (HVAC), lighting and water distribution systems.
United States of America	ASME NQA-1:2012, Quality Assurance Requirements for Nuclear Facility Applications [62]	Quality assurance system utilized for US NPPs and referenced in some other countries. See Ref. [63] for comparison between NQA-1-2008 and GS-R-3[a].
	Regulatory Guide 1.68, Initial Test Programs for Water-cooled Nuclear Power Plants [64]	Describes the scope and depth that the Nuclear Regulatory Commission (NRC) considers acceptable for initial test programmes for light water cooled NPPs. Appendix A lists plant SSCs, design features and performance capabilities that should be demonstrated during the initial test programme.
	Regulatory Guide 1.68.1, Preoperational and Initial Startup Testing of Feedwater and Condensate Systems for Boiling-water Reactor Power Plants [65]	Provides guidance the NRC considers acceptable when developing preoperational, initial plant startup, and power ascension tests for various light water reactor systems. It includes recommended tests for various systems for advanced boiling water reactors, economic simplified boiling water reactors, US evolutionary power reactors, US advanced pressurized water reactors and advanced passive reactors (AP1000).

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
	Regulatory Guide 1.68.2, Initial Startup Test Program to Demonstrate Remote Shutdown Capability for Water-cooled Nuclear Power Plants [66]	Provides guidance the NRC considers acceptable for demonstrating hot shutdown capability and the potential for cold shutdown from outside the control room.
	Regulatory Guide 1.68.3, Preoperational Testing of Instrument and Control Air Systems [67]	Provides guidance the NRC considers acceptable to implement preoperational testing of instrument and control air systems in an NPP.
	Regulatory Guide 1.09, Application and Testing of Safety-related Diesel Generator Units in Nuclear Power Plants [68]	Provides guidance the NRC considers acceptable for safety related diesel generators intended for use as on-site emergency power sources in NPPs. Includes information on site acceptance and preoperational tests.
	Regulatory Guide 1.20, Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing [69]	Describes methodology the NRC considers acceptable for vibration assessment of reactor internals during preoperational and initial startup testing.
	Regulatory Guide 1.41, Preoperational Testing of Redundant Onsite Electric Power Systems to Verify Proper Load Group Assignments [70]	Describes methodology the NRC considers acceptable for verifying proper assignment of redundant load groups to related on-site power sources.
	Regulatory Guide 1.79, Preoperational Testing of Emergency Core Cooling Systems for Pressurized-water Reactors [71]	Describes methodology the NRC considers acceptable for preoperational testing of emergency core cooling systems in pressurized water reactors.
	ACG Commissioning Guideline [72]	Guide for building owners, design professionals and commissioning service providers for HVAC and other building system commissioning.
	ANSI/NETA ATS-2013, Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems [73]	Guidelines on how to determine suitability for initial energization of electrical power equipment and systems and to specify field tests and inspections that ensure these systems and components perform satisfactorily, minimizing downtime and maximizing life expectancy.
	ANSI/NETA MTS-2011, Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems [74]	Provides guidance in specifying and performing the necessary tests to ensure that these systems and components perform satisfactorily, minimizing downtime and maximizing life expectancy.
	ASHRAE Guideline 0-2013, The Commissioning Process [75]	Describes the commissioning process capable of verifying that a facility meets owner project requirements. Contains procedures, methods and documentation requirements, in reference to commissioning, for each phase of project delivery from predesign through plant acceptance, occupancy and operation.
	ASHRAE Guideline 1.1-2007, HVAC&R Technical Requirements for the Commissioning Process [76]	Provides detailed commissioning guidelines for HVAC systems.
	ASHRAE Guideline 1.5-2012, The Commissioning Process for Smoke Control Systems [77]	Provides detailed commissioning guidelines for smoke control systems.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
	ASHRAE Standard 202-2013, Commissioning Process for Buildings and Systems [78]	Describes how to plan, conduct, and document the commissioning process for buildings and systems. Appendices provide sample documentation, including checklists, system manuals, reports and training plans.
	ASTM E2813, Standard Practice for Building Enclosure Commissioning [79]	Provides practices for building enclosure commissioning in two levels (fundamental and enhanced).
	BCA: Best Practices in Commissioning Existing Buildings [80]	Defines qualities and characteristics of best commissioning practices for existing buildings.
	BCA: New Construction Building Commissioning Best Practice [81]	Defines qualities and characteristics of best commissioning practices for new buildings.
	CCC: California Commissioning Guide: New Buildings [82]	Provides guidance on the commissioning process for new buildings.
	CCC: California Commissioning Guide: Existing Buildings [83]	Provides guidance for commissioning of existing buildings.
	USDOE: Continuous Commissioning Guidebook [84]	Provides guidance to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.
	GSA: The Building Commissioning Guide [85]	Provides a road map and recommendations for navigating the commissioning process from its necessary inclusion in project planning to its continued relevance throughout the life of a facility.
	IES DG-29-11, The Commissioning Process Applied to Lighting and Control Systems [86]	Provides commissioning guidelines for lighting systems and related controls.
	NEBB: Commissioning of Commercial Refrigeration Systems Guideline [87]	Establishes uniform and systematic criteria for commissioning when applied to refrigeration systems.
	NEBB: Procedural Standards for Whole Building Systems Commissioning of New Construction [88]	Establishes uniform and systematic criteria for the commissioning of buildings and environmental systems.
	NECA 90-2009, Recommended Practice for Commissioning Building Electrical Systems [89]	Suggests standardized procedures to commission new or retrofitted electrical systems and equipment. Provides a standard process for commissioning building electrical systems and provides sample guidelines for obtaining optimum performance.
	NFPA 3, Recommended Practice on Commissioning of Fire Protection and Life Safety Systems [90]	Addresses administrative and procedural concepts of fire protection and life safety system commissioning and provides direction on integrated system testing.

TABLE 1. SAMPLE NATIONAL AND INTERNATIONAL REGULATIONS, CODES AND STANDARDS RELATED TO NPP COMMISSIONING ACTIVITIES (cont.)

Country/ organization	National regulation, code or standard related to commissioning	Comment
	NIBS Guideline 3-2012, Building Enclosure Commissioning Process BECx [91]	Describes a process that provides the flexibility for owners to incorporate building enclosure commissioning into their project. The building enclosure commissioning process is utilized to confirm that the performance of materials, components, assemblies, systems and design achieve the objectives and requirements of the owner as outlined in the contract documents.
	USDVA: Retro-commissioning Process Manual [92]	Provides guidance for planning, acquisition and performance of retro-commissioning of facilities.
	USDVA: Whole Building Commissioning Process Manual [93]	This publication provides a framework for the verification of new installations and the performance of systems to be commissioned from the viewpoint of optimizing energy performance, protecting and conserving water, enhancing indoor environmental quality and reducing the environmental impact of materials.

[a] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006). This publication has been superseded by GSR Part 2 [5].

[b] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety in Nuclear Power Plant Operation, Including Commissioning and Decommissioning, Safety Series No. 50-C-O, IAEA, Vienna (1978). This publication has been superseded by SSR-2/2 (Rev. 1) [8].

[c] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning Procedures for Nuclear Power Plants, Safety Series No. 50-SG-O4, IAEA, Vienna (1980). This publication has been superseded by SSG-28 [2].

4. COMMISSIONING PROCESS

4.1. OVERVIEW

Commissioning occurs between construction of a facility's systems and their takeover by the operating organization for commercial operation. It can progress at various rates and at various times for different systems, and it can have distinct stages within a given system. Preparation is critical to success, with the careful validation and acceptance of installation completion records, the finalization and validation of commissioning procedures and the completion of personnel training all being important prerequisites. The general process for commissioning a system for a new NPP is shown in Fig. 6. Commissioning for smaller modifications and refurbishments follows a similar process with inapplicable steps deleted.

Commissioning test sequences are such that:

- Completion of one test or test phase ensures that the following tests or test phases can be conducted under safe conditions.
- Chronologically, from the preliminary test phase to initial core loading, more and more completed functional assemblies are brought into operation, aiming at replicating normal operating conditions as much as possible.
- System commissioning generally starts with auxiliary systems to ensure their availability to support the main systems before they are commissioned. Most component and system tests for new NPPs are performed under cold conditions.

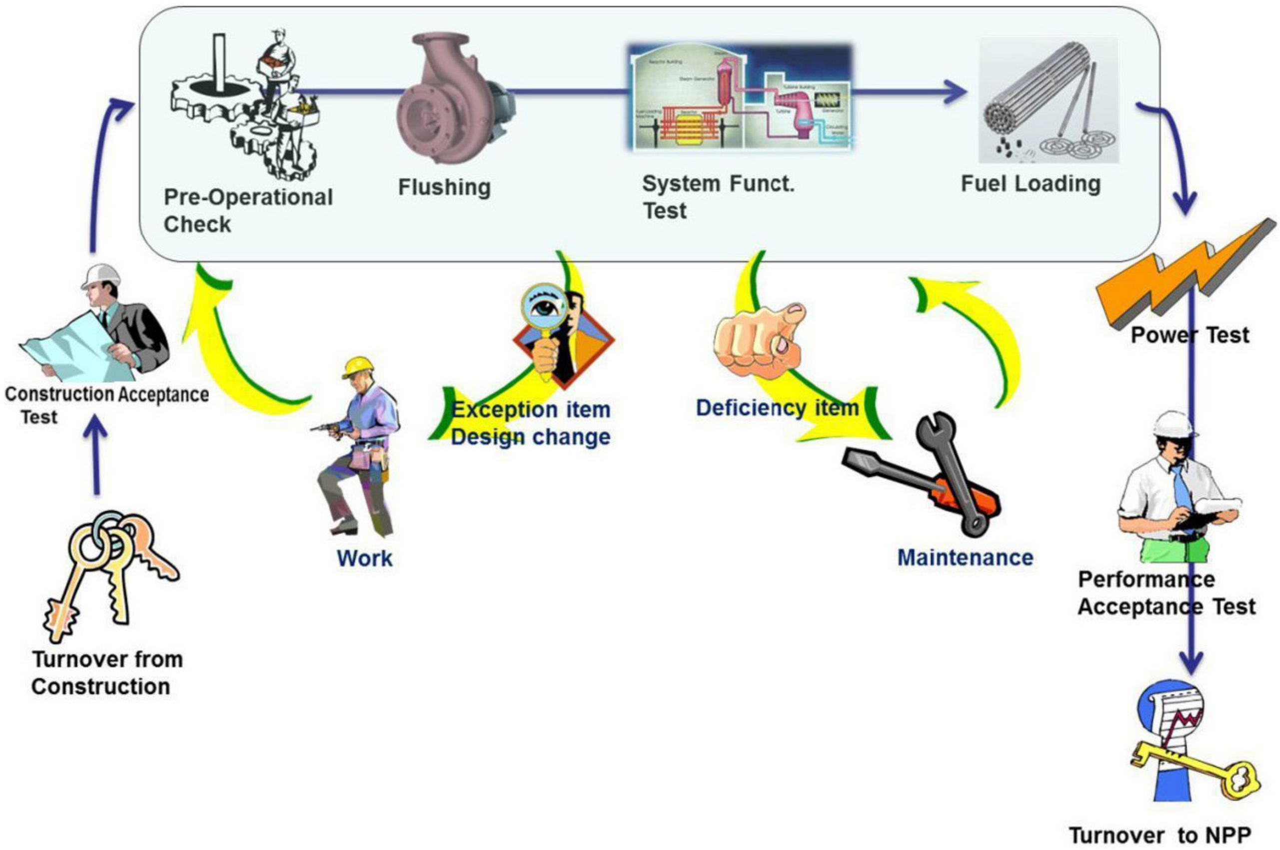

FIG. 6. Commissioning and turnover process for a new NPP [94].

— System testing generally is completed before proceeding with initial core loading operations, hot functional tests and plant startup. Tests performed on equipment or functional assemblies that can only be installed or completely tested after these steps are usually the only exception. This applies, for example in a pressurized water reactor, to the rod cluster control actuation system, which can only be completely installed after fuel loading. Complete commissioning of such systems can only be performed after core loading and before first criticality.

Commissioning tests start after the transfer of a system or subsystem from the construction organization to the commissioning organization. This follows final installation checks and tests (such as pressure tests, electrical tests and simple component tests). Before accepting the system/subsystem, commissioning staff carry out a check of construction completeness using walkdowns and checklists. These verify that the system/subsystem and all its components have been correctly installed. The phase is concluded with the commissioning organization formally accepting the installation status, which usually includes a list of open items. Owing to the need to use them during the construction period, permanently installed cranes, hoists and other lifting devices are often commissioned by the construction organization and then later turned over as fully commissioned.

Commissioning activities include establishing and staffing the commissioning organization, establishing the commissioning management system and related documentation (including a system to manage and record completion of activities), developing and reviewing commissioning documentation, scheduling commissioning work, setting up test conditions and running the required tests, recording and evaluating tests results, and then turning over the commissioned systems to operations.

Commissioning tests for new NPPs start with the so-called ‘preoperational test phase’ or ‘non-nuclear test phase’, which includes all checks, monitoring activities, adjustments, component settings, component tests and individual system functional tests. Then before fuel loading, commissioning staff carry out integrated system and overall plant functional tests under cold and then under hot conditions.

Fuel loading is typically authorized by the plant regulator, following assessment of commissioning tests and plant conditions. With the fuel loaded, the commissioning organization can then implement the so-called 'operational' or 'nuclear testing' phase.

The nuclear testing phase covers fuel loading, pre-critical tests, criticality and power escalation tests in steps up to nominal power. This typically starts with: measurement and validation of major core physics parameters, calibration of nuclear instrumentation channels, and functional tests of conventional island equipment and systems (turbine generator, pumps, heaters, etc.). After the normal operating tests have been completed, control loop performance tests under transient conditions are carried out for the different operating modes. This is followed by final adjustment of unit parameters.

The commissioning test stage ends with a demonstration of unit performance with regard to startup, shutdown, reduced load operation, load following capabilities and unit flexibility. This demonstration of plant performance is generally concluded with a continuous performance test and a trial operation run for a specified duration (typically at least one month).

The remainder of this section provides further information on many of these activities. The annex to SSG-28 [2] and Appendix II of this publication provide more detail on commissioning phases and test sequencing, as well as typical examples.

4.2. PREPARATIONS FOR COMMISSIONING

4.2.1. Establishing a commissioning organization and management system

An initial step in starting commissioning preparations is the establishment of a documented commissioning organization and associated management system that meets applicable national and international standards (as discussed in Section 3). Specific documentation needs are discussed in Section 4.2.2.

Human resources and organizational models are discussed in Section 5. A key point is that it takes years to develop the personnel required to staff such organizations, so planning for staff recruitment, training and development needs to be part of the overall national human resource strategy for the nuclear programme.

The commissioning management system includes procedures, organizational structures, administrative arrangements and associated resources. The successful implementation of a commissioning strategy requires a good management system.

Establishment of the management system needs to occur well in advance of the start of formal commissioning activities and be integrated into the overall project schedule. Commissioning activities may rely upon inspections and tests done at the factory during component fabrication (especially for complex or critical components that undergo detailed factory acceptance testing), so commissioning strategies and processes need to be well established prior to fabrication, and should be available during detailed design.

4.2.2. Establishing documentation requirements

As discussed in Section 3.3, establishing documentation requirements for commissioning is a key activity, and the structure, content, extent and control of such documents need to be defined (para. 5.1 of SSG-28 [2]). Section 5 of SSG-28 [2] provides recommendations for the scope and structure of typical commissioning documentation based on experience and lessons learned by a group of commissioning experts from various countries. These recommendations could be useful for newcomer countries or for improving country practices. The publication identifies typical organizational and technical documentation related to commissioning.

The type and level of detail of documents used for commissioning can be graded (see GS-G-3.5 [7] para. 2.41). For example, the level of detail required for a safety related system in a design document may be greater than that for a non-safety related system. The number of inspections or hold points on a non-safety related system may be fewer than for a safety related system.

The following sections present examples of practical arrangements applied in various countries related to the structure and content of such documentation based on SSG-28 [2] and other experience.

4.2.2.1. Management system manual for commissioning (commissioning manual)

The management system manual for commissioning, or commissioning manual, defines the management structure and organization, and the documentation guidelines for commissioning. It details rules and the responsibilities of the owner and supplier organizations during commissioning. Higher level documents define the overall programme, interfaces and logic, and more detailed documents address specific field activities.

The following items should be included in commissioning manuals (from para. 5.9 of SSG-28 [2], with examples added):

— The objectives of commissioning;
— The management policy of the operating organization;
— The responsibilities of participating organizations with regard to the commissioning of the plant (interfaces between construction, commissioning, operations, NPP supplier, design, training, supply chain and other organizations; organizational prescriptive authorities; etc.);
— The organizational structure for commissioning (organization charts, reporting relationships, etc.);
— The management for commissioning (e.g. conduct of tests, equipment and area jurisdiction control, handover processes, applicable codes and standards, maintenance and test equipment control, training and qualification requirements, procedural compliance, deviation/change processes);
— The commissioning programme (e.g. overview of commissioning steps, major milestones, hold points);
— Safety aspects (e.g. nuclear, radiological, industrial occupational health and safety, environmental protection, security aspects);
— The change management process for deviations detected during commissioning (non-conformance processes, unexpected event management processes, etc.);
— Arrangements for the documentation for commissioning (form, content and processes for managing commissioning documentation).

As commissioning progresses, additional processes and procedures may be added to the commissioning manual to address newly identified safety issues or risks, improve efficiency, describe new or temporary processes, or better define interfaces, roles or responsibilities.

4.2.2.2. Administrative procedures

Administrative procedures concerning the conduct of commissioning support those in the commissioning manual in ensuring its proper implementation. They may cover such areas as communications protocols or business management processes such as records and controlled document numbering and filing processes, shift work arrangements and new staff orientation. They may also include processes for administering worker protection permits (equipment isolation or lockout/tagout) or administering training, processes allowing operation of equipment or systems prior to complete plant turnover, or instructions or templates for preparing and formatting commissioning related documentation.

4.2.2.3. Commissioning programmes and procedures

Following preparation of administrative instructions for commissioning, technical procedures and plans governing execution and evaluation of commissioning tests are prepared. These include "basic information on the principles and objectives of the plant commissioning tests as well as details of the testing to be carried out on the plant" (see para. 5.11 of SSG-28 [2]). This section covers the structure of the commissioning programme and the various procedures and other documents associated with it.

(a) Commissioning programme

The operating organization ensures the development and implementation of the commissioning programme for each power plant unit. The regulator may require approval of this programme depending on the licensing framework. Such a programme is typically defined by describing the overall plant commissioning programme, those of individual systems (or groups of systems), and the commissioning phases or stages. Each of these is described in turn below.

(i) Overall plant commissioning programme

The overall plant commissioning programme provides a general overview of the commissioning process for an NPP, what phases or stages it is divided into and the overall schedule. Such programmes may have the following structure and content:

- Commissioning organization;
- Qualification and training requirements and schedule;
- Technical documentation, including commissioning procedures (and a schedule for their development);
- Commissioning phase/stage sequence and content;
- System commissioning programme list;
- Commissioning report;
- Safety requirements;
- Schedule for turnovers to operations.

(ii) System commissioning programme

System commissioning programmes provide objectives, principles, test conditions and acceptance criteria for tests to be performed on the system(s) concerned, including references to documents to be used for testing (test guidelines, test procedures), stages during which they are performed and their logical sequence. They are developed for each SSC and finalized well before (e.g. at least 3 months ahead of) the start of any inspections or tests.

System commissioning programme documents thus identify the:

- Commissioning organization responsible for implementing inspections and tests.
- Requirements and timing for supplier or owner representatives to witness inspections and tests.
- Commissioning objectives and scope (e.g. a list of items to be inspected or tested, and applicable equipment clearly indicated on system drawings such as system flow diagrams, electrical one-line diagrams and I&C control diagrams).
- Target start dates and durations for SSC commissioning based on system turnover deadlines.
- Necessary commissioning prerequisites, including, for example:
    - Electric power supplies necessary for running tests and conducting inspections;
    - Isolation of systems;
    - Sources of service water or other water;
    - Temporary modifications;
    - Temporary instrumentation;
    - Special procedures, test equipment or user/installation manuals;
    - Completion of other installation or testing activities.
- Roles and responsibilities of people involved.
- Format of inspection and test records.
- Acceptance criteria.

A system commissioning plan consists of the system commissioning programme and the set of test procedures to be used for system test implementation. It also includes a schedule with the proper sequences; references to applicable design, safety and licensing documentation; needed permits and support items such as scaffolding or temporary modifications; required support system availability; and inspection and test requirements.

(iii) Stage or phase commissioning programme

Commissioning is usually divided into stages or phases, such as preoperational tests, individual system functional tests, containment tests, cold and hot functional tests, initial criticality, grid connection and power increments. Paragraph 5.14. of SSG-28 [2] states:

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

In some jurisdictions such programmes may be subject to regulatory review. Therefore, they need to be prepared well in advance of the dates when the applicable commissioning will start. Submission time, structure and document titles can vary from country to country.

Stages of commissioning programmes are delimited by commissioning control points (hold points), which are generally at the beginning or end of stages of commissioning activities. Examples of commissioning control points are the start or end of activities related to primary circuit pressure testing, primary circuit recirculation cleaning, containment pressure testing, main reactor equipment inspection (following installation), hot functional testing, boron acid filling of primary circuit, initial criticality or grid connection. Results are to be reviewed prior to proceeding past the hold point to the next stage.

During development of a commissioning programme stage, possible changes in test scope and sequence (for example owing to postponement of an activity), and the implications of the possibility of having to concurrently conduct construction and commissioning activities during a stage, need to be considered.

(b) Detailed commissioning procedures and documentation

Within each commissioning stage there are detailed procedures for the execution of field activities and testing, and associated acceptance criteria and completion reports that confirm that these requirements have been met. The number of commissioning and test procedures for an NPP can be large. The scope, size and content of such procedures can vary, however for example for water cooled, water moderated type NPPs, about 800 test procedures are typically expected; over 3000 commissioning procedures were reported for a Canada deuterium–uranium (CANDU) reactor project (Qinshan) [95]; and an NPP in Japan required 167 tests as part of and prior to cold functional testing, 31 as part of hot functional tests, 12 related to the approach to first criticality and 67 post-criticality startup tests [96].

These procedures are based on vendor specifications, design basis and safety analysis reports, requirements of the regulatory body, licences, relevant statutory documents and good engineering practice. The documents are prepared in cooperation with engineering, operations and maintenance staff, and individuals responsible for plant licensing. The extent of the tests and data collected for each system is proportional to its safety significance and operational requirements. As described in Section 2.2, the aim is to ensure that commissioning provides objective evidence that SSCs installed meet all safety and design requirements.

Commissioning activities are typically activities important to safety, and as indicated in para. 4.26 of SSR-2/2 (Rev. 1) [8], they are performed in accordance with approved written procedures. Levels of procedural review will reflect the safety importance of the applicable components. Verification involves the operating organization as well as designers and the regulatory body, if necessary, in particular in reviewing validity of acceptance criteria (see paras 5.15 and 5.16 of SSG-28 [2]). Tests or experiments that may place the plant outside its safe analysed envelope must not be entertained, and changes to approved procedures need to follow a change control process and be duly authorized.

Test procedures and schedules are typically developed prior to (typically 3 months before) the start of commissioning activities to allow participants to become familiar with the test procedures, sequence of activities and requirements. Efficiency can be gained by developing model or template procedures for repetitive commissioning of similar SSCs (see Section 4.2.2.5). Having pre-developed procedures does not, however, necessarily mean that they cannot be modified or improved. There is typically room for improvement at the start of any enterprise. A change control and feedback system will allow for corrective action and improvements to procedures as experience is accumulated.

Testing may occur at numerous times for the same component in order to address all commissioning requirements. For example, a mechanical piping system with a motorized valve installed may undergo at separate times post-installation equipment and system cleaning procedures, pressure testing, individual equipment test procedures (e.g. valve stroke tests), system functional tests (e.g. operation to confirm required flow rates) and tests related to a specific function (e.g. operation of system logic and components in response to a simulated plant event).

Commissioning testing can include activities such as:

- System checks, system cleaning and pressure tests;
- Electrical and I&C commissioning of valve actuators and other power operated devices;
- Commissioning of measuring loops, protective interlocks and automatic controls;
- Commissioning of individual components;
- Commissioning of related systems or subsystems;
- Testing and optimization of closed loop and functional group controls;
- Testing and optimization of interlocks in connection with process controls.

Typical documentation associated with commissioning testing includes commissioning specifications, commissioning test guidelines, commissioning test procedures and test reports. These are described in detail in Sections 4.2.2.4 to 4.2.2.7.

Where commissioning work is contracted by an owner/operator to a third party, it is important that the typical content and level of detail expected in such documents be understood by both parties at early stages. This will prevent any disagreement as to what is acceptable. Previous acceptable sample documents can assist in this process.

4.2.2.4. Commissioning specifications

A commissioning specification or commissioning specification objective document is often prepared for the whole plant, specifying the main safety objectives to be verified. Individual commissioning specifications would then be written for each system to be commissioned. Commissioning specifications contain design, safety and analysis requirements to be demonstrated during commissioning, and their applicable acceptance criteria. They assist testing staff in preparing detailed commissioning test procedures and in reviewing the completeness and correctness of commissioning results.

Acceptance criteria are specified indicators or measures used in assessing the ability of a component, structure or system to perform its intended function. They include expected results of prescribed tests, and usually consist of a range of acceptable values and tolerances. Any verification done under a commissioning activity will need to have a corresponding acceptance criterion.

Some organizations differentiate between ‘soft’ and ‘rigid’ acceptance criteria. For example, the expected electrical power consumption of control rods (with a tolerance band) can be called a ‘soft’ acceptance criterion, in that it is not critical to control rod operation but must be enveloped by any design assumptions regarding overall electrical loading. Small deviations outside of expectations may be resolved by design staff. This is in contrast to a ‘rigid’ acceptance criterion for rod insertion time that is critical to nuclear safety and that design staff would not be able to resolve. In either case, however, field staff must be given clear indication of what acceptable results are, and when to involve design staff in result interpretation and analysis.

When all system tests, observations and measurements are complete and recorded, a responsible individual prepares a test report (see Section 4.2.2.7) to formally document results, analyse them and compare them to acceptance criteria in the corresponding commissioning specification.

A sample commissioning specification is included in Appendix VI.

4.2.2.5. Commissioning test guidelines

For recurring commissioning activities, commissioning test guidelines (also called commissioning worksheets or repetitive commissioning procedures) may be prepared as templates for test preparation and execution. Use of such validated guidelines helps improve the quality and efficiency of the commissioning process, since improvements and best practices can be incorporated into the standard guide as experience is gained. Guidelines can cover civil, mechanical, electrical, I&C or chemistry tests across a variety of systems.

Depending on the level of detail in the guidelines, the document can be used either as a model that needs to be adapted for field use in a specific application or directly as a field use procedure once it is confirmed applicable. Some example applications for guidelines include standard motor starter or circuit breaker commissioning checks, calibration procedures, valve actuator tests, instrumentation loop checks, interlock checks, insulation tests, torqueing procedures, system foreign material exclusion, cleaning and flushing procedures, fire barrier inspection procedures and tests, and others.

Typical test guidelines include information on what has to be observed, how to proceed in each case, what to test, which records must be used, etc.

Usually, commissioning test guidelines describe the scope of work that must be performed for the corresponding commissioning activities. The commissioning programme will document the guidelines used to perform the work, with a short description of the most significant verifications.

4.2.2.6. Commissioning test procedures

Commissioning test procedures are used to direct field activities related to commissioning and to record necessary results. Preparers of such procedures need to be knowledgeable about the system being commissioned and about how work is performed in the plant environment. These authors need access to a wide variety of documents related to the SSCs being commissioned. These may include:

— Final safety analysis report;
— System design descriptions;
— Design requirements, design drawings and other documents;
— Commissioning specifications;
— Commissioning test guidelines;
— Operating manuals;
— Periodic test procedures;
— System flow diagrams;
— Operational flowsheets;
— Instrument and relay calibration procedures, set points and tolerances;
— Measuring data sheets;
— Closed loop control descriptions;
— Functional diagrams;
— Design change information;
— Work reports (for similar equipment or for previous commissioning);
— Manufacturers' manuals;
— FAT records;
— Receipt inspection non-conformance reports and their resolution;
— Equipment spare parts lists;
— Maintenance procedures;
— Reference commissioning programmes and instructions from other plants, or model commissioning programme and test procedures;
— Construction turnover documents and check and test procedures;
— Internal and external experience and lessons learned for similar SSCs.

The name and format of test procedures can vary from plant to plant. They may be referred to as test procedures, commissioning procedures, commissioning instructions, workplans, etc. Regardless of names and formats, formal test procedures need to contain the objective of every activity, prerequisites to perform it, a description of the conduct of the activity, and acceptance criteria. For simple tests, formal procedures may be excessively burdensome. In such cases, simple work instructions can suffice. However national regulations may require commissioning test instructions for each commissioning test.

Commissioning procedures may be initially prepared in draft form using preliminary design information; however, they should not be finalized and issued prior to design completion. This includes a full review and incorporation of any as-built field information from the construction phase.

Test procedures should comply with a published procedure writer's guide and be user friendly. Standards for procedure format, place keeping, use of abbreviations, etc. should be developed. Sources of information on writing quality technical procedures and on their use include Refs [97–100]. Various 'plain writing' guides from non-nuclear sources (e.g. [101–103]) can also be useful in producing test procedures.

Paragraphs 5.19 to 5.32 of SSG-28 [2] provide a summary of topics that should be included in commissioning test procedures. The topics are listed below with some examples added:

— Introduction.
— Test objectives and methods (e.g. equipment or system(s) to be tested, overview, purpose of the test).
— Operational limits and conditions (e.g. precautions; critical limits; back out conditions or conditions to be maintained or respected during testing; special considerations such as foreign material exclusion, safe work planning, heat sink recall times, fire watch, confined space entry, environmental protection, radiological safety). See IAEA Safety Standards Series No. NS-G-2.2 [104] for more details.
— Prerequisites and initial conditions (e.g. commissioning stage (or substage) required for test, administrative and technical prerequisites for system to be commissioned, required system configuration (and required checks to confirm equipment alignment), impacted terminal or isolation points, requirements for other SSCs, special temporary instrumentation, equipment and materials necessary, required training and/or qualifications).
— Test conditions and procedures (e.g. specific components to be tested, detailed test sequence, operating procedures or other performance references to be used, requirements relating to procedure use and adherence).
— Acceptance criteria (what criteria are used, analysis method/process for test results, acceptable tolerances, immediate action to take if criteria not met).
— List of instrumentation and special test equipment (e.g. tool numbers, tool calibration requirements).
— Staffing, qualifications and responsibilities.
— Special precautions/contingency plan (e.g. industrial or radiological safety or environmental concerns, hazardous chemicals, back out conditions).
— Completion of test (e.g. duration or end point of test, state to leave system in following test completion or until commissioning results are accepted, cleanup and housekeeping requirements, other post-test requirements).
— Permanent records (records to be generated via this test such as filled in test forms, calibration sheets, etc.).
— Identification, cross-referencing and distribution (e.g. methods for processing and distributing test records).
— Data collection and processing (e.g. parameters to be recorded, methods and formats for collection and presentation of test data and results).
— Non-conformity management (e.g. process to deal with observed deficiencies).

Where possible, maintenance or test procedures that will be used for future post-commissioning maintenance or operations should be utilized during commissioning. This allows the procedures themselves to be validated, and provides good baseline results for plant operation.

Control of procedures and test forms is important during commissioning. A master copy of the procedure is often maintained, with a lead work group assigned control. Regular updates to the master copy are made by workers as the steps in the procedure are completed.

The Electric Power Research Institute (EPRI) has produced a guide to post-maintenance testing [105] that provides specific post-maintenance tests for various components of an NPP. While a typical post-maintenance test following a maintenance activity is only a subset of a full commissioning programme, such a guide can be useful for commissioning engineers in developing commissioning instructions. Various appendices in the guide cover specific details of testing electrical, I&C and mechanical components.

4.2.2.7. Test reports

Test reports (also called commissioning completion reports or commissioning reports) are used to document successful completion of commissioning activities. They confirm that required acceptance criteria have been met, and thus that system design and safety requirements are satisfied. They can document partial commissioning of equipment, systems or units at certain stages, commissioning of complete equipment or systems, or commissioning of the unit as a whole. The typical structure includes a list of applicable acceptance criteria and the commissioning results (e.g. completed test procedure steps or checklist items) that prove the criteria are met.

After completing each test phase of commissioning, it may be necessary in some jurisdictions to present the test reports to a commissioning committee and/or to the regulator, who accepts the results and authorizes the start of the next phase of commissioning. To save time, the reports can be prepared in draft, either prior to or coincident with test execution, and then updated with actual results (supporting measurements, lists, protocols, strip charts etc.) as final results are obtained. A special commissioning group for test evaluation and documentation can also assist in this process.

Test reports are useful to operations staff (engineers, designers, etc.) for future safety reviews or in troubleshooting possible system issues, and to designers to improve subsequent designs. With this in mind, test report authors often include in their reports additional information that may be difficult to locate at a future date, even though it may not be strictly necessary for the validation of acceptance criteria. This can include such things as baseline geometries, prerequisites related to the start of commissioning (e.g. certificates confirming equipment and system or unit readiness for commissioning), descriptions of testing done, detailed test results (measurements captured in field check sheets, strip chart copies, etc.), unexpected results, troubleshooting that was required, deficiencies discovered and recommendations on their resolution, lessons learned and suggestions for future design or commissioning activities.

In some jurisdictions test certificates are issued to certify that certain testing has been completed in accordance with the established procedures. Similarly, stage completion certificates (listing associated test certificates) can be issued to certify that all the tests in the commissioning stage have been satisfactorily completed.

Appendix VII contains a sample test report.

4.2.2.8. Commissioning/completion management systems

Nuclear projects involve thousands of activities and ‘commissionable objects’ such as instruments, equipment, skids, modules, circuits, loops, subsystems and systems. Owing to the large volume and complexity of commissioning data, powerful commercial software known as commissioning management systems (sometimes called completion management systems) can be very useful. They are often integrated with general construction management systems. Such systems can help coordinate commissioning activities, enhance collaboration, and streamline turnover and the preparation of commissioning documentation.

Design of these computer tools can vary greatly, from desktop based applications that need to be installed on a computer to web based systems that allow project information to be accessed from any device with network capability. Screenshots from a sample commercial application are shown in Fig. 7.

Systems that link to NPP enterprise systems offer the added benefit of integrating commissioning data into the NPP’s master data repository for future reference.

4.2.2.9. Records

Records management is an important part of any large project, and this is especially true during the commissioning phase. Capturing, indexing and storing commissioning related records, and integrating them into operating organization permanent records, are key project activities. Such records are preferably stored in an easily retrievable electronic format.

SSG-28 [2] section 5 details a number of important records generated during commissioning. These include test reports (also called commissioning reports; see Section 4.5.3.1), stage reports (for test phase completion see Section 4.5.3.2), reports of deficiencies and reservations during commissioning (blocking items/open items/punch lists; see Sections 4.4.4 and 4.11.3), certificates (see Section 4.5.3.2), plant and system handover documents (see Sections 4.7 and 4.8), and other supporting documentation (e.g. calibration records for instruments and maintenance and test equipment).

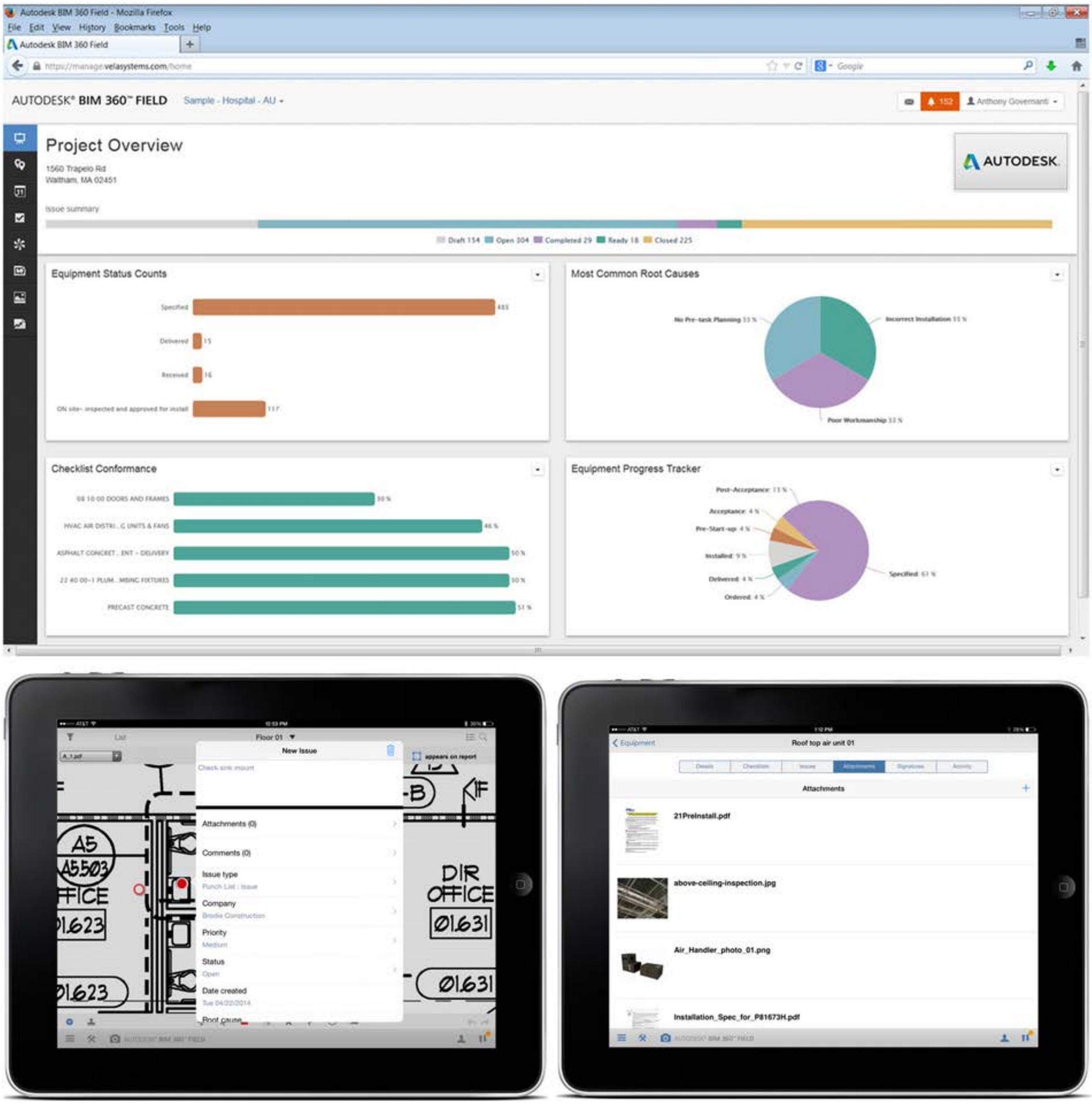

FIG. 7. Sample screens from a construction field management system (BIM 360 Field™ screenshots reproduced courtesy of Autodesk, Inc.).

4.2.2.10. Operating organization documentation requirements

When commissioning is complete, the operating organization requires substantial engineering, operations and maintenance documentation to safely and efficiently operate the turned over SSCs, and eventually the NPP as a whole. The commissioning organization is typically required to provide specific system documentation to the operating organization as part of the system turnover process. Requirements are typically documented in a checklist to be reviewed and accepted as part of the turnover. Paragraph 4.42 of SSG-38 [9] provides guidance on the level of technical detail needed in transfer documentation, indicating that it “should be sufficient to allow the licensee to identify parts and order replacements for maintenance”.

Increasingly, such facility information is produced and managed electronically. Examples include correspondence, cost estimates, purchase orders, operations and maintenance manuals, installation instructions, spare parts data, analyses, drawings and computer aided design models. However, much electronic information is still held in documents that do not have a formal structure. Most correspondence, including project reports and drawings, falls into this category. Advanced systems can now provide facility information in a structured form that is immediately machine interpretable. This development advances productivity and reduces errors. Fiatech's Capital Facilities Information Handover Guide [106] discusses these issues in relation to information handover. It defines a methodology for defining the information requirements for the full facility life cycle and then developing and implementing an information handover plan for a specific capital facility project.

Some features related to specific commissioning documents are described in the following sections.

(a) Operating procedures

Operating procedure lists are typically initially defined by the NPP design organization. For example for water cooled, water moderated type NPPs, about 300 operating procedures are usually developed. Operating procedures are based on design documentation and are reviewed and agreed upon by interfacing organizations. The reactor designer, NPP designer and organizations responsible for quality assurance, emergency preparedness, oversight and technical supervision of NPP design will typically review and approve the reactor (construction) installation, operating manual, emergency operating procedures (including severe accident management or beyond design basis accident procedures), emergency preparedness plan, fuel handling and storage procedures, and others as appropriate.

The operating organization, in consultation with design and commissioning staff, is normally responsible for the development of permanent operating procedures prior to the start of SATs and commissioning activities (for example three months prior to the start of testing). Commissioning steps need to be set up to validate these operating procedures. Similarly, mechanical, electrical and instrument checklists in operating procedures need to be used when practical to establish initial conditions for preoperational tests and to restore equipment to its normal state following test completion.

Periodic tests used to demonstrate the continuing validity of the licensing envelope during operations are normally defined, at least at the conceptual level, by the original designer. These tests are integrated, verified and validated during commissioning. A good way to accomplish this is to incorporate periodic tests or critical portions of these tests into system preoperability checks. To minimize field issues, such tests are typically thoroughly reviewed at their field location and subject to a tabletop run-through review as part of test preparation.

It is likely that permanent plant procedures will require revision based on system preoperational test results, since actual equipment performance can be different from what was expected prior to the tests. These revisions are also subject to validation (i.e. simulation, mock-up, walk-through or field execution of the procedure by operations staff with heightened awareness that there may be unknown issues that need to be addressed before the procedure is considered 'correct').

(b) Operational flow diagrams or operational flowsheets

Operational flow diagrams or operational flowsheets are diagrams used by the operating organization to visualize connections between piping or electrical elements. Based on as-built design drawings, they are used for plant operations (e.g. operating procedures), controlling plant configuration, and worker protection (e.g. establishing isolation boundaries for lockout/tagout functions). Increasingly, such operational flowsheets are moving from being simple drawings to being part of on-line/computerized systems that are linked to enterprise equipment information databases. Such computer systems can assist with maintaining control over operable plant equipment (valves, circuit breakers, etc.).

Requirements for the content of operational flowsheets and the processes for keeping them updated should be defined by the operating organization as part of the management system. Such operational flowsheets need to be updated to reflect design changes implemented prior to and during the commissioning process.

(c) Operating commissioning logs

Operating commissioning logs are used to monitor commissioning activities and work permits, register actual commissioning processes and preliminary results, control activities of commissioning and operating personnel, reflect equipment and system status, and provide data for development of test reports. This helps to ensure that commissioning proceeds efficiently, accurately and safely.

Requirements for log keeping are established by the commissioning and operating organizations. Such logs are increasingly implemented using computerized tools, allowing easier access to log information for all facility staff. Master copies of commissioning test procedures need to be kept up to date (refer to Section 4.2.2.6).

(d) Maintenance related documentation

Maintenance related documentation is required for commissioning and for later routine maintenance by the operating organization. Commissioning staff need equipment maintenance and calibration instructions from the vendor to assist in equipment set-up and initial testing. New plant routine maintenance, periodic inspection and calibration procedures derived from vendor maintenance manuals and other sources can be tested during the commissioning period to ensure that they are practical for regular use.

A preventive maintenance programme should be ready and put into place following completion of initial system commissioning. This ensures that the commissioned equipment does not deteriorate before final plant handover to the operating organization. Depending on equipment ownership, this programme may be set up and implemented by either the commissioning organization or the engineering and maintenance groups within the operating organization.

(e) Engineering documentation

Commissioning organizations often have to confirm that appropriate design documents and related information are available for handover to engineering groups within the operating organization. These can include design requirements, design descriptions, as-built design drawings, technical specifications, design calculations, plant models, calibration set points and tolerances, and procurement related engineering information (see Part (f)). Much of this information is required by commissioning staff to adequately prepare commissioning test procedures (see Section 4.2.2.6); commissioning staff also have the role of ensuring that any changes made during the commissioning process are reflected in the information provided at the time of system turnover.

(f) Procurement and spare parts related information

Commissioning organizations often have to confirm that appropriate information on procurement and spare parts is available for handover to the operating organization. They also have a need to ensure that commissioning spares are available to support equipment replacements that may be needed during the commissioning phase.

Readily available component specifications and procurement information for the supply of spare parts are necessary for the operation of an NPP. This body of information is increasingly stored in electronic format in enterprise databases that are capable of linking upstream design data with work management functions, operating functions (operating procedures), personnel protection functions (work permits, lockout/tagout functions, etc.), procurement, warehousing and other functions. An integrated system with a single source of equipment data will reduce errors and facilitate safe operation.

Detailed requirements for supply of such documentation and population of enterprise systems are developed as part of the planning and contracting phase for any nuclear project. This ensures that the supplier understands the enterprise requirements, and builds into contract pricing the resources needed to provide such required information in the correct format. More details on procurement related data needs are included in IAEA Nuclear Energy Series No. NP-T-3.21 [3].

4.2.3. Scheduling

Commissioning schedules define activities, durations, sequences and due dates for each commissioning task. They may be developed at different detail levels. These may include an overall commissioning schedule, stage specific schedules, system commissioning schedules and detailed schedules for specific commissioning activities. A sample schematic overall commissioning schedule and a schedule for major milestones only for different NPP projects are shown in Figs 8 and 9. Deliverables needed for turnovers to the operating organization (documentation, training requirements, etc.) need to be scheduled and tracked.

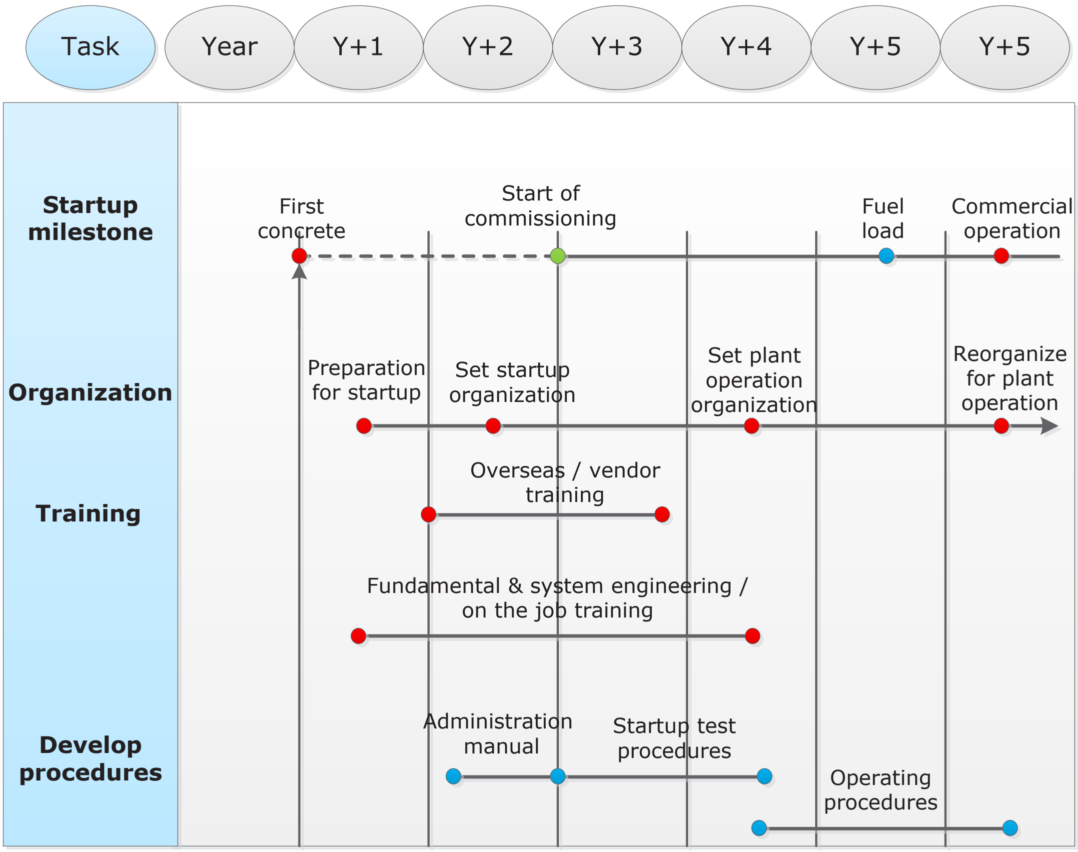

FIG. 8. Sample overall commissioning schedule for a first NPP.

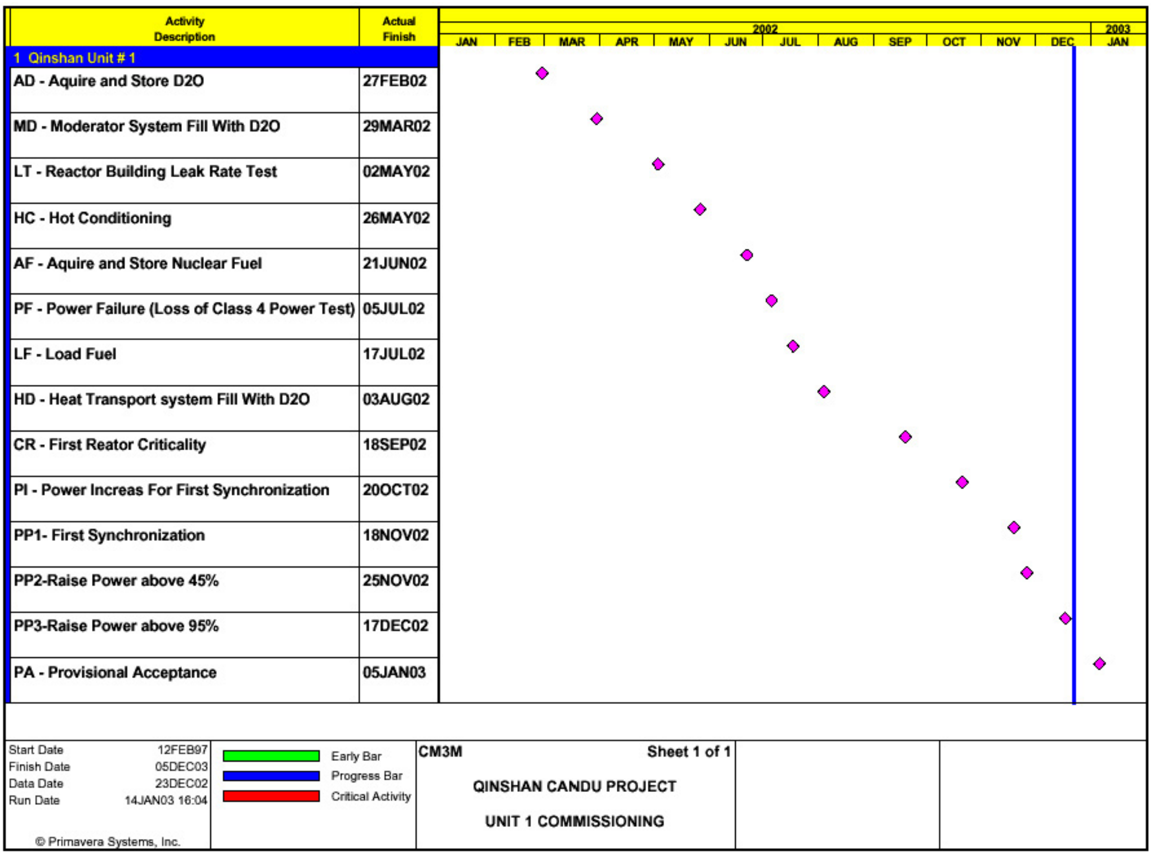

FIG. 9. Main commissioning milestones (Qinshan Unit 1) [95].

National regulations and standards may require an overall schedule that includes design, construction, commissioning and operating organization activities. Even where not required, a common schedule is helpful to provide common milestones for use by construction, commissioning and operations personnel. The schedule should be negotiated between all parties involved and be aligned with critical path activities. It can be useful to develop the overall project schedule backwards in time from the date the NPP needs to be handed over based on the expected commissioning schedule. Figure 10 provides a sample diagram showing a hierarchy of project master schedule levels. Level 1 is the project master schedule, Level 2 shows summary schedules, Level 3 shows critical paths, and Levels 4 and 5 show increased detail for different time horizons.

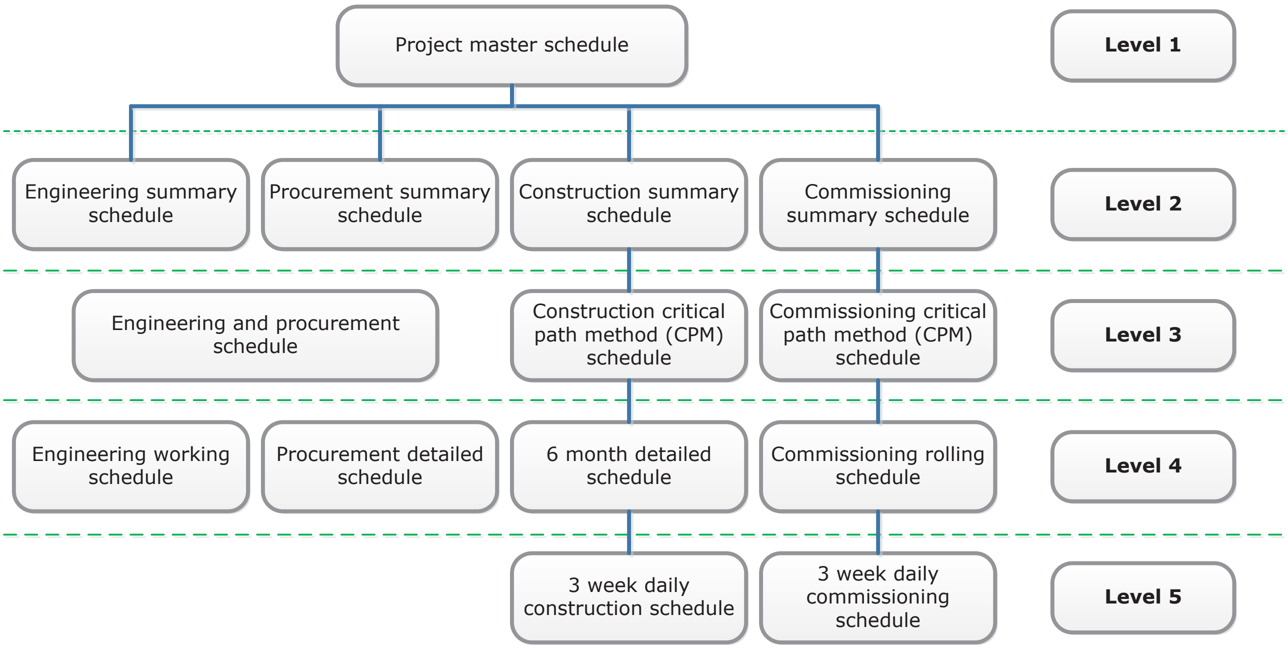

FIG. 10. Project master schedule hierarchy.

Scheduling personnel need to be qualified and experienced and have good awareness of the potential impact of their activities on the safety and quality of commissioning. A poor schedule can put the facility or personnel at risk.

Commissioning activities need to be sequenced in a logical order and the schedule regularly updated to reflect results obtained, technical issues and changes in the availability of human and material resources. A good practice is to hold regular meetings between all organizations involved to draft the schedule and review the sequence of near term activities for the coming 1 or 2 weeks. Once major testing commences, or whenever it is deemed necessary, daily meetings are normally held to review ongoing activities. Scheduling needs to ensure that systems and equipment essential to maintaining industrial safety (e.g. lighting, fire protection, communications, equipment tagging) are given adequate priority.

Changes in test sequence need to be carefully controlled to ensure that checks are in place to confirm that all prerequisites have been met and that unusual or less than optimal plant configurations utilized to progress commissioning work for schedule or economic purposes are avoided. Hold points corresponding to major steps such as fuel loading, initial criticality, power increases and plant acceptance are typically established.

There is often a tendency to schedule commissioning activities using the most optimistic timelines. Complex systems in a nuclear facility often require periods of troubleshooting during commissioning, and schedules that are too short can put undue pressure on commissioning staff to rush their activities. A strong nuclear safety culture can offset some of this, however realistic commissioning scheduling is necessary.

4.2.4. Interface requirements

The commissioning organization needs to interface with the engineering, safety and licensing organizations during the preparation of commissioning documentation.

During commissioning, all issues related to design, manufacturing and equipment performance need to be recorded and related records need to be maintained. Design and manufacturing issues are documented as they are discovered. A commissioning clarification request process can be developed for this purpose. Inquiries are typically forwarded to an engineer who is responsible for obtaining clarification, when required, from design engineering. If the response from engineering requires a setting or configuration change, engineering will develop a modification package to implement the change.

If changes involve safety related pressure retaining components, or a system reclassification for pressure boundary components, then a submission for registered pressure retaining components is made to the regulator or to local authorities. These typically include a reconciliation statement and a justification for the change, engineering statements, any analysis reports and evaluations, and any drawings.

As soon as authorities approve the modification package, it is delivered to the commissioning organization, and once it is implemented (which may involve construction and commissioning staff again), the engineer can close the commissioning clarification request. Issues related to equipment performance are addressed through a record form that is often called the commissioning quality observation record (or equivalent). This record will trigger action to address non-conformances related to failed tests or failed equipment. If replacement parts are not stored, and failed equipment cannot be repaired, new procurement will have to be initiated.

4.2.5. Evaluating readiness

Prior to starting commissioning activities, the responsible organization typically conducts a commissioning readiness evaluation. Areas to evaluate include those related to the construction installation turnover process, the commissioning process itself, and the process for turnover to operations.

Readiness subjects related to the construction installation turnover process are defined in table II.7 of IAEA Services Series No. 24 [107]. These include reviews of the turnover documentation including walkdown records, methods to handle hold points, methods to track open items, plant labelling and boundary control methods, inspection of items that will become inaccessible and processes for interim maintenance of operating equipment.

Readiness subjects related to the commissioning and the related turnover to operations process can include:

- Definition of formal roles and responsibilities for commissioning;
- Existence of formal documented processes for plant testing of equipment and systems;
- Existence of maintenance procedures, tooling, and call-ups to support systems being placed into service;
- Existence of formal processes for documenting commissioning completion and system availability for service, and for transferring such information to records;
- Verification that commissioning completion activities and records will provide assurance that system design requirements are met;
- Verification that test requirements and methods are well-defined and independently reviewed, ensuring test results are validated against acceptance criteria;
- Verification that processes are in place for tracking and completing open items to be carried into the operational phase;
- Verification that processes are in place for ensuring commissioning completion activities are complete prior to turnover of systems;
- Verification that adequate processes are in place to establish and maintain effective boundaries between turned over and not turned over SSCs;
- Verification that necessary regulatory and plant interface prerequisite activities have been completed (e.g. NPP regulatory authority approvals have been obtained, commitments have been met (nuclear, environmental, grid connection, etc.), interface protocols and procedures are in place);
- Verification that necessary operational procedures for items such as worker protection, tagging and preventive maintenance are in place prior to handover to operations;

— Verification that processes are in place for addressing non-conformances and corrective actions, including independent and senior management oversight.

The United States Department of Energy has published a standard for planning and conducting readiness reviews of its facilities [108]. The process was developed to provide a high degree of confidence that operations at new and restarted Department of Energy nuclear facilities will be conducted as intended by the design and safety basis. A graded independent review approach is used. Independence was deemed necessary to avoid conflicts of interest that could compromise reviewer ability to objectively determine the status of the proposed operation. In a section on guidelines for developing the startup or restart plan, the standard emphasizes the importance of identifying facility management observers for initial operations oversight, and confirming equipment operability, procedure viability and operator performance during the commissioning and startup phase.

4.3. FINAL INSTALLATION TESTING

Final installation testing or construction acceptance testing consists of a series of inspections, checks and tests performed by the construction organization prior to turnover of the applicable systems to the commissioning organization. The division of responsibilities regarding construction acceptance testing activities between the construction and commissioning organizations may not be the same in all jurisdictions, and so depending on the chosen commissioning approach and the capabilities of each group, some 'final installation' activities described in this section may be done by commissioning organizations, and some activities described as 'commissioning' activities later in Section 4.5 may actually be done by construction organizations.

Some jurisdictions have specific industrial safety regulations regarding the startup of new equipment or processes. Such regulations often require what are called 'pre-start health and safety reviews', which require written reports by qualified individuals (typically professional engineers) that detail the measures (steps, actions or engineering controls) necessary to bring the related construction, addition, installation or modification into compliance with applicable industrial regulatory provisions regarding exposure to chemicals or other designated substances, and other hazards. The pre-start review would also confirm that these measures have been adequately put into place. Such controls might include physical protective elements such as machine guards and emergency stop devices, or the design of racks, stacking structures, hoists, spray booths, or chemical process systems to conform with applicable published codes and standards. Where pre-start health and safety reviews are required, they need to be completed prior to the final installation testing or commissioning steps at which the applicable hazard would become relevant.

4.3.1. Civil system installation testing

Civil system installation testing ensures that such systems meet their critical installation requirements, with special attention paid to safety significant structures such as the containment system; fire barriers; flood barriers; tsunami, tornado and seismic protection provisions; and access routes to secondary control areas. Major structures made of reinforced concrete (e.g. water intake and outflow channels, cooling towers, water filtering systems, ventilation ducts, special foundations, security barriers) are also typically subject to inspection. Inspection check sheets are typically provided with the turnover of the corresponding system.

In recent years, building envelope commissioning, also called building enclosure commissioning (BECx), has become more common for civil structures. BECx strives to ensure that components that make up the building envelope (i.e. items that separate the external from the internal environment such as the building roof, skylights, walls, doors, windows and foundations) meet owner requirements. BECx is discussed in detail in Section 4.5.2.3, however key activities that can be performed as part of construction installation checks include inspections and verifications that proper components and installation methods have been used, and that initial assemblies or mock-ups have been tested for air or water leakage.

4.3.2. Mechanical process system installation testing

For mechanical process systems, final installation testing generally involves system cleaning and pressure tests. It is advisable to perform system cleaning before pressure testing, because shut-off valves are usually used to isolate the zone to be pressurized, and if debris is present in the system then valve seats may be damaged.

Different cleaning methods are used, such as blowing compressed air through the system, hydro-jet cleaning, sweeping with demineralized water, or circulating water using system pumps or external temporary pumps. For special systems such as lubricating systems, fuel oil systems and control fluid systems, chemical flushing may be necessary.

Pressure tests verify the mechanical resistance of welds, the absence of leaks and the absence of plastic deformations in system components. They are done in accordance with relevant pressure boundary standards, and generally using the same medium as that used during normal operation. Systems that work with air are tested with air, systems that work with oil are tested with oil, and so on, except in the case of toxic or caustic fluids, such as sulphuric acid. Tests done with water (called hydrostatic tests) are most common. Pneumatic tests (using gases) are more hazardous than hydrostatic tests. The hazards result from the air or other gas used for pneumatic testing having very high potential energy when compressed. Any minor leak path can lead to an immediate rupture and blast, releasing the energy with a sudden explosion. The time from identification of a leak to failure can be very short, making it almost impossible to take remedial action. Pneumatic tests are thus typically used on small, low volume systems only when the system cannot be filled with water, or when even traces of a different testing medium cannot be tolerated.

To conduct a pressure test, the system is usually divided into several test zones, making use of convenient physical boundaries or divisions in test or design pressures. Various zones can be combined if they can be tested at the same test pressure. Devices that may be damaged by the test (owing to overranging) are disconnected or blanked off. The sections are pressurized to the required test pressure (often 150% of the system design pressure). The system is checked for a slow decay in pressure following initial pressurization that would be indicative of a leak.

Although not strictly a test, an important verification typically conducted at this time is to confirm that the process system installation (piping route, orientation, flow direction, etc.) matches 100% with system design documentation.

Further information on mechanical process testing is provided in Section 4.5.2.4.

4.3.3. Electrical system installation testing

For electrical and I&C systems, applicable electrical tests are insulation property measurements (e.g. insulation resistance (Megger), dielectric absorption, polarization index, hi-pot testing), checks of contacts and motor windings, circuit breaker timing tests, transformer turns ratio and polarity tests, electrical protection interlock checks, visual checks at current transformer circuits (not to be kept open), visual checks at voltage transformer circuits (all links to be closed), setting and calibration of electrical protection equipment (relays, breakers, thermal cut-outs, moulded case circuit breaker testing, etc.), phase sequence checks (e.g. motor bumping), ground impedance testing and ground electrode resistance measurements.

Additional verifications performed at this time include:

— Confirming point to point wiring compliance with electrical cabinet drawings, electrical circuit drawings, cable lists, cable connection lists and one-line diagrams;
— Confirming compliance with other design documents and applicable norms related to construction of power cabinets and switchgear cubicles (e.g. anchoring, labelling, connection torque settings, conduit and cable entries, grounding, availability of safety/rescue equipment).

Stationary batteries require inspections to ensure proper connections and polarity, proper electrolyte levels, proper specific gravity, and the availability of charging and ventilation circuits. Publications of the Institute of Electrical and Electronics Engineers (IEEE) such as Refs [109–113] can provide further guidance. Of special note is the need to not leave stationary batteries off charge for extended periods of time, as might occur in a warehouse or following installation while awaiting commissioning. This can cause damage or loss of battery capacity.

Therefore, careful scheduling and coordination is required regarding delivery of batteries from the manufacturer, their installation and their commissioning.

Further information on electrical testing is provided in Section 4.5.2.5.

4.3.4. Instrumentation and control system installation testing

For hardwired I&C components, documents such as functional diagrams, circuit diagrams and wiring diagrams are provided. Installation verifications are performed for wire and cable continuity, polarity and insulation resistance for cabinets and field instruments. Protective interlocks are also checked, as are measuring and control loops, set points and calibrations.

In some cases, on-site point to point verifications can be skipped if identical FATs were witnessed by commissioning specialists. However, many aspects of FAT testing are only for contractual purposes, and FATs are not always credited as part of commissioning testing. One reason for this is the potential for equipment to be damaged between the factory and the final installation site.

If any such FATs are credited, they need to include assessment and documentation similar to those for site tests. Of particular concern is the case when factory tested equipment interfaces with complex nuclear facility systems (field inputs and outputs, alarms, etc.), since unexpected issues may not be reliably simulated and detected in a factory setting.

I&C commissioning has two important parts:

— One part is related to plant I&C systems, such as the reactor protection system, reactor limitation system, neutron flux measuring system, radiation monitoring system and alarm annunciation system.
— The second important part is related to the verification of the I&C portion of process systems. This includes verification of field instrumentation and checks of compliance with instrument allocation drawings, measuring loops, closed control loops, protective interlocks, control desks and control panels.

Further information on I&C testing is provided in Section 4.5.2.6.

4.4. TURNOVER FROM SYSTEM INSTALLATION TO COMMISSIONING

4.4.1. General

Following completion of installation activities, SSCs are transferred from the construction/installation organization to the commissioning organization. Paragraph 4.41 of SSG-38 [9] describes provisions that are established and implemented to control and coordinate this handover. These include the following:

“(a) Documentation relating to the items to be transferred should be reviewed by the construction organization and the receiving party for completeness and accuracy.
(b) Tests to ensure that the structures, systems and components have been constructed, manufactured and installed in accordance with design specifications should be carried out and the results should be recorded.
(c) Any remaining non-conformances or incomplete items should be identified and assessed to ensure that there will be no safety implications during commissioning activities.
(d) Any outstanding work should be agreed, planned and scheduled.
(e) Termination points, which identify the boundaries of transferred systems and equipment, or transferred parts of systems and equipment, should be clearly identified in transfer documentation, together with the associated required configuration (for example, open/close of valves).
(f) An inspection of transferred items and associated records and documents should be conducted.
(g) The transfer of responsibilities should be recorded.
(h) Approved as built plans should be transferred together with adequate and precise configuration details for the installation.

(i) All structures, system and components transferred should be marked or tagged in accordance with the documentation.
(j) All temporary devices should be identified."

Construction and commissioning activities on a site typically need to overlap. This may induce risks for personnel and equipment if ownership and accountability for equipment operation are not clearly assigned to one organization or the other. Formal turnover processes between the construction organization and the commissioning organization are the way in which equipment ownership and operation are controlled. When equipment and systems are turned over, all accountability for the transferred items is moved to the commissioning organization. This includes accountability for their operation, maintenance and testing, as well as any associated worker protection activities (i.e. lockout/tagout requests).

Where the operating and commissioning organizations are separate, the operating authority for systems and equipment (including worker protection) typically resides with the operating organization, even during commissioning. This allows the application of the operating organization processes for worker protection to all SSCs from the start of plant commissioning through plant startup and commercial operation.

There are two main types of turnover from the installation/construction organization that concern commissioning: (a) area turnovers, and (b) system turnovers. Each of these is discussed in turn below.

4.4.2. Area turnovers

Most NPPs are constructed using an installation area scheme that concentrates on physical areas. Such an approach focuses on finishing a particular building, structure or room (e.g. screenhouse, water treatment plant, turbine building, control room) and the work of the specific disciplines within it (e.g. mechanical, electrical and I&C installations within the screenhouse).

Area turnovers are designed to transfer physical ownership of a region of the power plant to the operating organization. Following turnover, the operating organization has control of the area, controlling access to the area and any activities within it. Such turnovers do not imply a complete turnover of all systems within the area, as certain non-turned over equipment (i.e. certain pipes, electrical cabinets, etc.) may not be completely installed and may need to be turned over later to the operating organization.

This turnover process is described further in section 4.2 of IAEA Nuclear Energy Series No. NP-T-2.7 [94]. Applicable standards may require that rooms, structures or buildings be accepted by the operating organization before the commissioning organization can proceed with commissioning activities within those areas.

As part of the area turnover process, construction and operations staff conduct a joint walkdown that covers such items as area housekeeping, industrial safety, area access control (access routes, keys and locks, etc.), and room and equipment labelling. Any deficiencies will be corrected or added to a turnover open item list as is done for system turnovers. Once the area is in an acceptable state and formally turned over, any further activities within the area require operating organization authorization. A typical walkdown checklist and building turnover form are provided in Appendix IV.

These turnovers do not typically cover civil system commissioning that might be required for structures within the applicable rooms or areas. Such commissioning, for example of containment structures and anchorages, would typically be the subject of a civil system turnover to the commissioning group.

4.4.3. System turnovers

In the latter part of the construction process, a functional approach is taken that shifts the focus from an entire area or building to the completion of specific systems or parts of systems. In the example of the screenhouse mentioned in Section 4.4.2, a functional approach would mean finishing all work on, for example, the trash screen system (civil, mechanical, electrical and I&C) but not necessarily on the whole screenhouse that contains it. Transition and transfer processes would in this case be organized to facilitate this system by system transfer. To minimize the potential for confusion surrounding the extent of equipment ownership, electrical and I&C turnovers are normally done at the same time as the corresponding mechanical process system turnover.

The principles and process commonly applied for the transfer of systems from construction to commissioning are as follows:

- During construction, the commissioning organization defines its requirements and needs related to system transfer. This can include subdivision of the installation into functional multi-discipline turnover packages with clear:
  - Delimitation of turnover package boundaries;
  - Identification of mechanical, electrical, I&C and civil components within the turnover boundary;
  - Documentation of any particular requirements related to the installation status (e.g. unusual 'as-left' status items such as connections not fully torqued that will be disassembled during commissioning; required design changes still to be installed; outstanding need for pre-turnover system activities such as calibration, cleaning, filling, venting and/or flushing);
  - Identification of priorities and targets for transfer.
- Within the construction and installation organization, a technical completion team responsible for the overall organization, supervision and follow-up of system completions, of transfers to commissioning and of the clearance of open items is set up with enough independence to be able to manage its work across the different construction disciplines. The same model is adopted for the commissioning implementation teams. Typically, the disciplines involved are civil (buildings and structures), mechanical (process systems), electrical and I&C.
- Construction/installation progress is coordinated and checked by construction supervisors to allow turnover from construction to commissioning at the required time.
- After completion of installation and before the official turnover, the commissioning organization performs a walkdown and check for every system. They are verified against system drawings, layout and erection drawings, and checklists related to readiness for commissioning. These inspections aim to detect deficiencies that could hinder turnover to commissioning before they impact the project schedule. Representatives of the operating organization may also participate in these checks, in particular for aspects related to system or equipment isolation and tagging.
- This transfer may be requested only for a system or part of a system for which:
  - Verifications and installation inspections at the end of construction have been performed for all construction disciplines.
  - Temporary or final labelling is complete.
  - System boundary devices (circuit breakers, isolating valves, isolating switches, blind flanges, etc.) separating turned over equipment from non-turned over equipment have been installed, defined, and clearly labelled or tagged.
  - Temporary isolation devices are installed as needed to isolate parts of the system to allow testing.
  - Required system boundary point conditions (e.g. valve/breaker positions) have been defined and processes to change their condition are in place (agreement of both construction and commissioning authorities is typically required).
  - An installation completion certificate related to the system has been provided. This includes documentation recording the installation status. In addition, a list of open items is prepared by construction staff, based on inspections performed during and at the end of construction.
- Construction, commissioning and operations personnel typically perform a joint final walkdown to validate the state of construction, system boundaries and the list of remaining construction open items, and to assess system readiness for starting commissioning activities. An example of a walkdown checklist is provided in Appendix IV.
- Applicable installation completion declaration packages and turnover documents have been approved by construction authorities and accepted by the commissioning authorities. As far as possible, the package covers all disciplines (civil, mechanical, electrical and I&C). A sample installation completion declaration package is given in Appendix IV.
- As soon as the turnover document has been approved, component and system commissioning can start.

Note that following the turnover to commissioning, construction staff will typically remain involved to complete any outstanding installation activities (open items), to complete outstanding or newly defined system modifications and to assist with test preparation as requested by the commissioning organization. All activities to be performed on the system in question will, however, be managed either by the commissioning organization through the issuance of test or work permits, or by the operating organization if so arranged.

If a system defect is detected after the system has been turned over to commissioning, either the commissioning or the construction organization (depending on the nature of the work needed) may be tasked to correct the defect in accordance with the work processes in effect for commissioning activities. System ownership would almost never be transferred back to the construction organization to correct defects, since this can lead to confusion over who is the operating authority for the equipment, and subsequently to injury resulting from unexpected equipment energization.

The process and implementation of system transfers is critical to overall project completion as they have a direct impact on preoperational tests and therefore on the overall schedule. Good preparation and coordination are key.

4.4.4. Turnover acceptance — blocking items and open items

Before the installation is turned over to commissioning, engineers from the commissioning organization perform a walkdown with construction staff, verifying the adequacy of the installation and checking for problems. Representatives of the operating organization may also participate in the walkdown.

Immediately following the walkdown and system turnover, the system is tagged to indicate that it is henceforth under the responsibility of the commissioning organization. This tagging is a warning for construction and other staff not to touch the equipment without formal permission from the commissioning organization.

If deficiencies are found during system walkdowns, they are typically resolved before turnover to commissioning. Depending on their nature, deficiencies may prevent turnover (‘blocking items’) or they may be added to an ‘open item’ list or ‘punch list’ that contains all items to be resolved for the system in question. Such a list is kept up to date by the applicable construction authority and commissioning system engineer. It is helpful if all open items are managed by the commissioning organization in a centralized manner, using a computerized support system.

Potential blocking items include:

- Missing or insufficient vents and drains;
- Pipe penetrations out of tolerance;
- Pipe slopes out of tolerance;
- Valves installed in wrong position or with wrong actuator position;
- Wrong flow direction in valves or heat exchangers;
- Cross-connected level or flow instrumentation lines;
- Distance between pipes and other components out of tolerance;
- Manual and motorized valves and actuators with insufficient maintenance envelopes;
- Missing/damaged cables, cable connection boxes or connection plugs;
- Damaged equipment;
- Improper labelling;
- Unsafe industrial safety conditions.

Open items are typically graded according to their severity, given target completion dates and milestones (e.g. before fuel loading or removal of shutdown guarantee), and assigned to a specific individual for resolution. The list at the time of turnover is usually included as part of the turnover document and reviewed by the operating organization at each commissioning process hold point.

A sample grading scheme for open items is:

- Class ‘A’: those blocking installation and associated checks and tests;
- Class ‘B’: those blocking system commissioning;
- Class ‘C’: those not blocking anything (can be resolved after system is put into operation, but must be resolved before final plant turnover to operations).

The open item list is kept up to date for the duration of commissioning until final transfer of the plant to the operating organization. A sample open item list is provided as part of Appendix IV.

4.5. COMMISSIONING TESTING

Commissioning testing can be viewed from different perspectives, as shown in Fig. 11. From a nuclear safety perspective, it can be divided into preoperational (before fuel loading) testing and operational (post-fuelling) testing, while from the perspective of specific equipment, it can be divided into individual system commissioning and phase commissioning. Each of these divisions will be described in turn below.

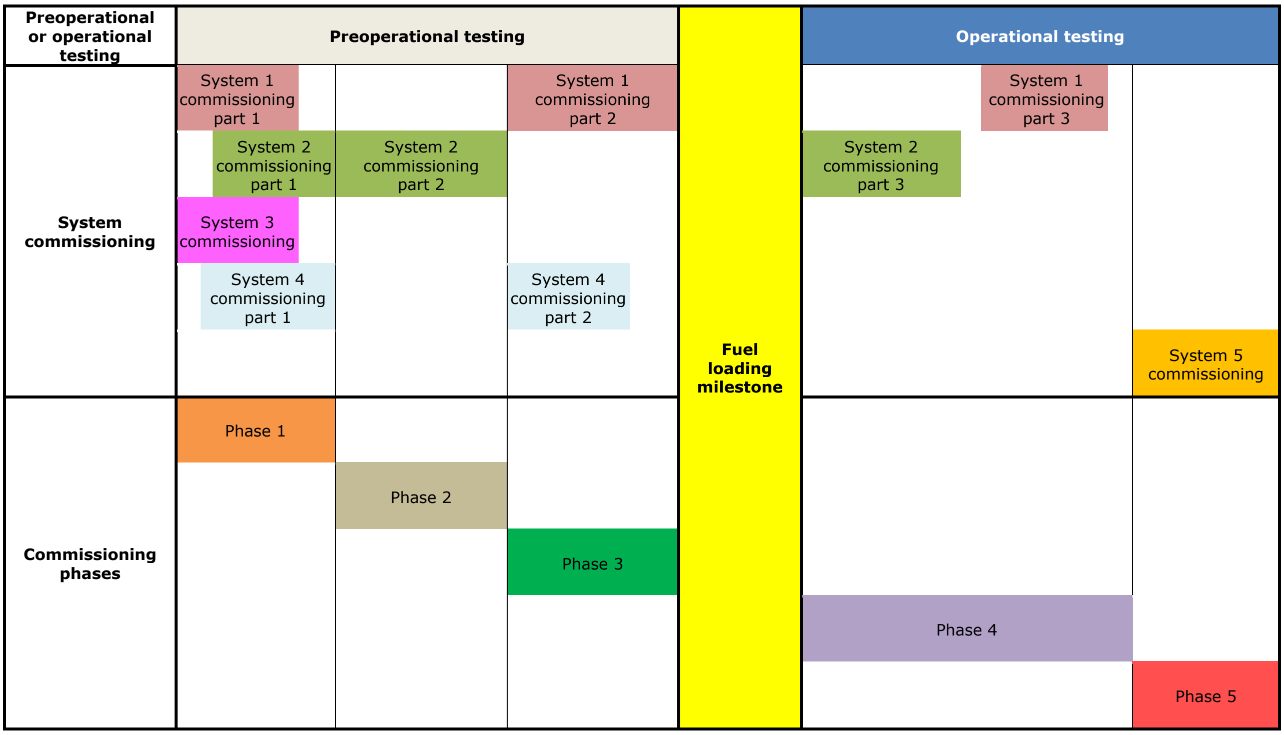

FIG. 11. Relationship between operational test phases, system commissioning and overall commissioning phases.

4.5.1. Preoperational tests, fuel loading and operational tests

Fuelling is a key milestone for an NPP project, and is the point where the NPP needs to have most of the systems and processes in place for its operation. Preoperational tests typically consist of individual system tests followed by integrated tests of systems performed first under cold and then hot conditions. The objective of the individual system tests is to check the operability of components and systems and to confirm that they meet required functionality and performance requirements. These tests are carried out mainly under cold primary circuit conditions.

Preoperational integrated system tests under hot conditions involve the reactor coolant systems, reactor auxiliary systems and other interconnected systems. These checks confirm their interaction and performance under operating system temperatures, flows and pressures. The heat necessary to increase the system temperature is provided by the main reactor coolant pumps recirculating the coolant in a closed loop.

After completion of these hot functional tests, final prerequisite checks and verifications are conducted in preparation for fuel loading. Initial fuel loading is subject to a specific authorization given by the operating organization and the regulator after their assessment of the plant and its condition (see para. 6.11 of SSR-2/2 (Rev. 1) [8]).

After initial fuel loading, operational tests (also called startup tests or nuclear tests) are carried out to confirm the performance of all systems and the entire plant. They typically include:

— Subcritical tests of the reactor system;
— Initial criticality and reactor physics tests at low power level;

— System functional tests at power conditions (such as level control test of the steam generators, control test of the turbine bypass valves and power rejection test);
— Power and reactor physics tests at several power levels;
— Power operation test at full power level.

During this operational testing, components and systems are tested to ensure they operate in accordance with the design specifications and that the plant can operate in a reliable and safe way during normal and accident conditions. This ensures that the systems designed to prevent and mitigate accident conditions operate properly.

4.5.2. System commissioning and commissioning phases

From the perspective of specific equipment, commissioning can be divided into individual system commissioning and phase commissioning. Individual systems need to be confirmed functional by a series of tests at different points in time (which may be before or after fuel loading). An NPP project is divided into phases for which specific aspects of commissioning need to be complete. Certain systems or portions of systems may need to be available and commissioned for each of these phases, and then certain integrated system commissioning tests are performed to ensure that the commissioned equipment and systems work correctly together. Some common examples of phases are the cold and hot functional test phases that are typically performed prior to fuel loading.

Scheduling and execution of tests are performed by the commissioning organization in accordance with the documentation described in Section 4.2.2. The commissioning organization ensures that test prerequisites are met and that adequate staff, appropriate tools and any temporary devices required are made available.

The commissioning organization typically informs the owner/operator and the regulator of scheduled tests so that they may witness specific tests if they so desire. If owner or regulator attendance for a given test is mandatory, it is the owner’s responsibility to ensure that timely attendance for the required tests occurs.

Before starting integrated testing at the end of the plant commissioning phase, the commissioning organization performs a review of test prerequisites, open items and associated closure documents to thoroughly validate the completion of individual system commissioning tests.

Overlapping of activities during the commissioning phases can occur. For example, peripheral system tests may be conducted at the same time as the integrated plant tests, and construction, operation and maintenance tasks may need to be performed in parallel. This can present increased risks for personnel injury, equipment damage and schedule delays if specific controls for the various organizations have not been established. The controls can include specific work scheduling, authorization and control processes used by the organizations.

A good practice is to set up a commissioning committee to oversee such activities. Such a committee includes representatives of all involved parties, with key operations staff particularly well represented. This group has overall responsibility for the operation of the integrated systems and of the unit as a whole. Section 5.3 provides more information about the constitution of a commissioning committee. Operations involvement in the committee is important, because these phases are a particularly appropriate time for hands-on involvement of future operations staff and an efficient way to provide real life on-reactor training to the permanent reactor operators and to their supervisors.

4.5.2.1. Preparation for system testing

Once a test procedure is approved, a lead test engineer or test director is assigned to coordinate all organizations in verifying the test prerequisites, such as the initial calibration of permanently installed instrumentation and controls, installation of special measuring and test equipment, alignment of mechanical and electrical equipment, and any other steps necessary to achieve required initial test conditions. Once the test preparations are complete, the test director coordinates with scheduling personnel and the interfacing organizations to make the required crews available to conduct the test.

Considerable time can go by between approval of a test procedure and completion of all prerequisites. It is thus helpful prior to test commencement to verify that there have been no changes to the system configuration or any adverse impact from other testing activities that would require a change to the test procedure. Once this verification is completed, the test can be performed.

As set out in Section 4.2.2.3, a good practice is to gather in one document, the system commissioning programme, all test requirements related to a system. This would cover all phases of commissioning. This practice makes it possible to have an overview of the scope, content and sequence of system functional tests and allows for an effective demonstration of system test completeness.

The following sections focus on practical arrangements and lessons learned in the areas of preparation, execution and validation of system commissioning tests.

4.5.2.2. Conduct of system testing

The conduct of commissioning is similar to many operations or maintenance activities at a power plant. Normal practices for the safe conduct of operations and maintenance need to be followed (e.g. adherence to safety guides related to operations [114] and maintenance [115]).

Following approval of the test and prior to actually performing it, the test director holds a pre-job briefing. It is designed to ensure that participants understand their role during the test and any test expectations. Communication methods, conditions requiring halting of the test, 'go/no-go' decision points and industry operating experience related to the test are reviewed.

For commissioning of safety related channelized systems, the possibility of commissioning staff making the same error on multiple channels should be considered. Different staff can be assigned to work on the different channels, since it is unlikely that different individuals would independently make the same error. Similarly, the risk of common cause failure relating to the supervisor can be eliminated by assigning each channel to a different crew.

Supervisory oversight is an important part of the commissioning process. Direct supervisory surveillance of each and every activity is not required when qualified personnel use approved procedures; however, supervisors are expected to do spot checks at a frequency sufficient to provide confidence in the quality of the work. The frequency and intensity of supervisory surveillance depends on the workers' qualifications and competence, the frequency at which the task is completed, and the potential consequences of errors. Other management oversight functions are also important, such as personal inspections and walkdowns by shift supervisors and other senior plant management.

Many tests last several shifts or even days. It is not unusual to encounter equipment problems or test result deficiencies which require the test to be stopped until a resolution is reached. For this reason, the test director often maintains a test record log so that important information can be easily communicated from one shift to the next.

When conditions cause a delay or require the test to be halted, the test director will promptly notify the operations shift manager.

Following resolution of the condition that caused the test to be stopped, the test director will again verify that the test procedure is still adequate, identify any new or changed conditions that could affect the test, coordinate with scheduling and other support organizations, perform another pre-job briefing and then complete the test.

When the active data collection sections of the test are completed, the test director promptly notifies operations staff and initiates any actions needed to return the equipment to its normal configuration. A prompt post-test meeting helps confirm that all necessary results have been recorded and there are no outstanding items left. Test results are then promptly transmitted to the organization responsible for reviewing and accepting them (typically the design organization).

4.5.2.3. Civil system commissioning

The largest structure to be commissioned is the containment building and its associated components. Acceptance of the containment building and associated components is conducted according to requirements of a special commissioning test programme and all applicable standards. IAEA Nuclear Energy Series No. NP-T-3.5 [116] on concrete ageing management discusses containment pressure testing issues.

BECx for building roofs, skylights, walls, doors, windows, louvers and foundations can include field or lab testing of building exterior components (often the first installed items or mock-ups) for water leakage (via standard test methods such as AAMA 501.2 [117], ASTM E331 [118], etc.), air leakage (ASTM E283 [119]), undesirable condensation, or structural performance (ASTM E330 [120]), and confirmation that appropriate construction phase inspections and checklists have been completed. Water testing can be done for all subassemblies used on a project, including siding, stucco, metal panels, concrete, louvers, door flashing, lintels, roof curbs, skylights, roof and wall penetrations, windows, parapets and expansion joints. Operable components, such as doors and certain windows, require function testing (ability to open/close with proper sealing), interior noise levels may need to be checked and confirmation is needed that energy efficiency or security related features are in place and that related mechanical systems (e.g. heating, ventilation and air conditioning (HVAC); drainage) function as designed. Interior rooms with equipment qualification requirements for leaktightness may require similar testing. Guides for BECx include Refs [79] and [91].

Civil structures or components are often commissioned in coordination with or as part of another discipline's commissioning programmes. For example, commissioning of a security access door control system might include steps to check the door's structural integrity and operability.

4.5.2.4. Mechanical system commissioning

Mechanical process system commissioning typically involves ensuring the capability of such systems to perform their design functions, such as being able to provide adequate flow during operating and emergency conditions. Where measurement devices are not permanently installed as part of an NPP's design, temporary ones may be needed for commissioning.

Mechanical commissioning can take up more than 50% of all commissioning resources. It includes all checks, adjustments, settings and functional tests required to ensure compliance with design requirements and to guarantee that nuclear commissioning can be initiated under conditions that are as safe as possible.

Component commissioning includes mechanical activities as well as associated electrical checks. Typically, this includes component cleaning (by blowing with compressed air, dynamic flushing with hydro-jets or circulating water), valve and actuator checks, lubricant checks, adjustment of protective devices, backflow prevention device testing, functional checks of electrical interlocks, and first start ('bump test') of pumps, fans and other equipment. Protective interlock verification is led by the mechanical process engineer and supported by I&C personnel.

During commissioning, temporary filters are often installed in systems to remove any debris remaining from the installation process. However, it is extremely important that flow verifications be undertaken to ensure that these methods have been successful. Foreign material can cause valves to not close when required or can clog pump strainers, and can cause subsequent delays to the commissioning programme while corrective actions are taken.

System tests include recording of equipment characteristics; determination of flow rates and pressure drop; reverse flow checks; verification of any additional protective interlocks, alarms and annunciations; verification of control loops and automatic functions; system trial run and optimization under specified boundary conditions; proof of performance of components, such as heat exchangers, degassers, driers, evaporators and filtering systems; verification of acceptable seal or seat leakage; and finally, testing of the combined interaction of several systems verifying whether measurements and alarms are consistent with the process. Such tests allow for the identification of the initial characteristics of systems and equipment, and provide baseline reference values for future periodic testing.

In addition to the verification that the system meets the original design criteria regarding flows and pressures, mechanical commissioning also involves verifying that no cavitation occurs in valves or pumps, pumps work at a suitable point on their characteristic curves, no water hammer or undesired pressure waves are produced, vibration in components and pipes is acceptable, displacements of pipes in cold and hot conditions are acceptable, recommended temperatures are not exceeded, plant chemistry is acceptable, etc.

The tests are conducted by stages so that satisfactory completion of one test ensures the safe performance of the following test. Each stage in this sequence also entails, wherever necessary, simulation of operating parameters that cannot otherwise be achieved.

The tests are conducted by first simulating various signals, and then bringing more and more complete functional assemblies into operation, and finally replicating as far as possible normal operating conditions.

When necessary, abnormal operating conditions and accident conditions should, if practicable, be simulated unless they jeopardize personnel safety, equipment integrity or the cleanness of the various systems.

Some of the most important tests in this phase are the primary circuit and secondary circuit pressure tests, HVAC tests, and the hot functional test.

During hot functional testing, the reactor coolant system is operated for the first time together with the reactor auxiliary systems, the turbine island and other systems, to check interactions of components and systems. This serves to demonstrate the operability and safety of the overall plant to the extent possible. This testing uses no nuclear steam generation, instead making use of the heat generated by the main coolant pumps. More information is provided in Appendix II.

HVAC commissioning typically consists at a minimum of ensuring proper air balancing in the system during normal and abnormal conditions, as well as proper temperatures and humidity control for both personnel comfort and equipment protection. Heavy water drier commissioning is important for pressurized heavy water reactors (PHWRs), and interfaces with fire protection systems need to be tested. Summer and winter mode verification may need to be completed at different times during the year, with worst case extrapolations supported by design calculations. There are numerous standards from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [75–78] and other organizations that can assist.

In the context of HVAC and building systems, retro-commissioning refers to performing commissioning for the first time on existing HVAC equipment in an older building. It may not be possible to base retro-commissioning on documented design numbers. If this is the case, it is best to balance the unit based on industry standards and comfort. Re-commissioning refers to commissioning HVAC systems that were already commissioned during the initial commissioning process, and is undertaken when the owner wants to verify, improve or document the performance of existing HVAC systems. Some jurisdictions require re-commissioning on a regular basis to ensure energy efficiency features remain operational [83]. This type of commissioning may include an analysis of building operating protocols, adjustment or calibration of systems, and any needed cleaning and repairs. Properly performed, retro- or re-commissioning also includes documentation and training so building operators can maintain any improved performance. Information on retro- and re-commissioning can be found in Refs [83] and [92]. Such processes are not common for nuclear safety related HVAC equipment, but may be needed for the balance of plant or commercial facilities on a nuclear site.

In recent years, buildings and systems have often been required to meet specific energy efficiency performance requirements (e.g. via the United States of America's Leadership in Energy and Environmental Design or the European Union's Energy Performance of Buildings Directive), either by design or by contract. This requires undertaking performance verification tests to demonstrate that the buildings perform as specified and deliver the contracted energy savings.

Hot functional tests are governed by normal operating procedures. Operation and maintenance personnel in all disciplines participate to the extent possible. This provides opportunities for operating personnel to gain familiarity with plant operation and provides an opportunity to validate operating procedures before the nuclear phase.

Appendix D of EPRI's guide to post-maintenance testing [105] covers mechanical testing of specific components.

4.5.2.5. Electrical system commissioning

Electrical commissioning is required for stationary electrical systems at NPPs (e.g. generators, auxiliary or standby power supply systems, inverters, transformers, uninterruptible power supplies, motor–generator sets, batteries, electrical protection cabinets, communication systems, distribution equipment, lighting and building services, lightning protection systems, grounding systems), and for the electrical components of all process systems (motors, valve actuators, electrical heaters, etc.).

During NPP construction, the unit is typically tied into the grid prior to initial unit startup and run up to provide power for station loads and to facilitate construction and commissioning activities. Prior to the start of commissioning, IAEA Nuclear Energy Series No. NG-T-3.8 [121] on grid reliability states that a final check should be made to ensure that all necessary grid additions and enhancements have been completed, and that they are consistent with the bid invitation specification and applications for construction or operating licences. Section III.4 of that publication provides a list of grid related questions to consider prior to commissioning. These address completion of grid studies, grid enhancements, grid operational procedures, agreements with other countries related to the grid and other issues.

Of particular importance is the need to validate the full load capability of electrical systems (design basis loading of buses or standby generators) under expected variations in grid or generator terminal voltages. NPP buses do not typically experience such extremes in electrical demand or voltages during normal operation or routine test conditions. External or temporary load boxes may need to be installed to complete such commissioning, and commissioning may need to be supported by design analysis. Similarly, confirmation is needed that equipment can be started in all required modes of operation.

Infrared thermography is a useful tool during electrical commissioning. It can be applied during high electrical load conditions to help detect unusual hotspots where poor or loose connections may be present. Such processes can also be used during routine predictive maintenance where access to terminals is available.

Following energization, electrical equipment should be observed for abnormalities (e.g. unusual noises or smells). It should be verified that voltage measurements fall within expected ranges. Phase sequences should be checked for correct rotation, and neutral currents should be measured. Current transformer secondary currents and phase angles should be measured. Directional tests should be done for directional protection. Stability tests should be done for differential protection circuits. On-load testing should be carried out for automatic voltage controllers for transformers, metering should be checked and auto-transfer or reclosing circuits should also be tested. Station batteries should be subjected to capacity and load profile tests as required, and charging circuits should be confirmed operational. Uninterruptible power supply systems should undergo component testing for the battery charger, the battery itself, transfer switches, circuit breakers and cables. Diagnostic, graphical user interface configuration, logging and alarm functions should be confirmed.

Commissioning of electrical components involves measuring such things as electrical consumption of motors, starting time for valve actuators, voltage drops, winding temperatures, vibration, inrush current for transformers and other parameters. Alarms, process logic, protective trips and interlocks should also be confirmed operational.

Some sources of typical electrical commissioning tests can be found in InterNational Electrical Testing Association (NETA) acceptance testing [73] and maintenance testing [74] standards, and IEEE battery maintenance and testing standards [111–113]. As discussed in Section 4.3.3, battery charging and commissioning should begin as soon installations is complete (which should be done immediately upon battery delivery). Appendix B of EPRI's guide to post-maintenance testing [105] covers electrical testing. International Electrotechnical Commission (IEC) standard 62382 [122] and ANSI/ISA-62382 (IEC 62382 modified) [123] from the American National Standards Institute (ANSI) and International Society of Automation (ISA) cover electrical and I&C loop testing.

For lighting circuits, illumination levels should be checked to ensure that they match design calculations for 'new' conditions (i.e. bulbs not degraded, fixtures clean, etc.), and control circuits (occupancy sensors, dimming circuits, etc.) should be checked to confirm that they function correctly. Information on lighting control commissioning can be found in IES DG-29-11 [86], developed by the Illuminating Engineering Society (IES) in association with the Lighting Controls Association as a supplement to ASHRAE 0-2013 [75]. In critical areas where colour discrimination is important from a human factors perspective, the correct appearance of colours under the installed lighting system should be confirmed.

4.5.2.6. Instrumentation and control system commissioning

I&C commissioning involves on one hand the commissioning of specific I&C systems such as hardware cabinets, reactor protection and limitation systems, neutron flux measuring systems, radiation monitoring systems and human–system interfaces (HSIs), and on the other hand the commissioning of field instrumentation of all process systems. This field I&C is turned over to commissioning together with the corresponding process system to allow for the first startup of electrical equipment and process systems with active protection logic and alarms.

Typically, I&C commissioning involves:

- Commissioning of I&C cabinets (process information and control system, process automation system, safety automation system, etc.), main control room and emergency control room, and instrument signal conditioning and command interfaces;
- Verification of logic diagrams, protective interlocks and alarm annunciations;
- Verification of plant mimics (including correct configuration of software and graphical user interfaces);
- Calibration of analogue and binary measuring loops;
- Verification of closed loop controls;
- Checks and adjustment of motorized valves;
- Calibration of in-core and ex-core nuclear instrumentation and alarm thresholds of radiation monitoring equipment (see also Appendix II).

Commissioning should also include checks to ensure computer or cyber security features and functions have been implemented and are up to date. IAEA Nuclear Security Series No. 17 [124] provides information on computer security.

New systems with ‘smart instrumentation’ and ‘smart calibrators’ can save time and increase loop checking efficiency. With such systems, configuration and calibration is quicker and fewer paper records are necessary.

Appendix C of EPRI’s guide to post-maintenance testing [105] covers I&C testing. IEC standard 62382 [122] and ANSI/ISA-62382 (IEC 62382 modified) [123] provide information on electrical and I&C loop testing.

I&C system commissioning has a number of unique aspects owing to the recent increase in the use of digital hardware and software to control plant equipment, and in some cases, physical timing issues associated with both new digital and older analogue technology that uses relays and similar devices. Analogue devices take a definite time to open or close their physical contacts, while digital devices have a definite scan or execution speed in their internal subroutines. Neither of these impacts may be obvious from a system’s Boolean logic diagram. Items with software or digital controls can be subject to cybersecurity or software security issues, and set point or other changes can be inadvertently or deliberated made with no obvious external signs.

The United Kingdom’s Office of Nuclear Regulation has produced a guide specific to I&C aspects of nuclear commissioning [53]. Some key points covered by the guide are listed below (summarized or expanded). Certain of these items might be partly or fully included in factory or other testing of the particular equipment, or be dealt with during the detailed design process, and so not be subject to an in-plant commissioning test.

— During I&C commissioning, only parts of complete systems may be functional, or field conditions may not be those required (e.g. accident condition, worst case loading condition) to test the desired functions, so testing may be carried out under different circumstances than those prevailing during plant operation. Dummy inputs and outputs are sometimes used to mimic the influence of interfacing subsystems or of boundary equipment not yet connected, systems are forced into unnatural configurations (e.g. relays held or simulated closed or open) and assumptions are made about interfacing systems, all of which need to be shown not to invalidate the tests. Commissioning engineers should examine such cases carefully and challenge assumptions where there is doubt, since system behaviour is often different under fully dynamic operation than during relatively static testing.
— A reasonable range of ‘robustness’ type tests should be included, during which systems are subjected to a certain amount of abuse. This applies especially for systems that interface with operators. Inputs should be applied in the wrong order and all at once; range end values should be forced; zero, out of range, and invalid values should be used; and values corresponding to failed sensors should be used. The aim is to give confidence that systems can tolerate operator and interfacing system faults without becoming deadlocked or failing in some other way. The scope of such testing should be related to the complexity and safety criticality of the system: the more complex or safety critical the system, the wider the scope.
— Ergonomic aspects (including task analysis assumptions such as which operations are to be performed and how often, procedures used, inputs and alarms) of control stations should be tested in conjunction with human factors specialists, as should other operator interfacing arrangements such as alarm response strategies.
— Extent of input and output range and combination testing should be examined, since usually only partial ranges and relatively few combinations are tested, with the assumption being made that all others will produce similar results.
— It should be verified during integrated testing that full end to end tests (including logic, sequence and timing aspects) are carried out for instruments, controls and protection systems (i.e. from sensor to display and/or actuator). It should further be ensured that no system required for safety is considered available for its safety function until such tests have been carried out fully.
— Long duration tests should be included for equipment that must function for prolonged periods. A system may function effectively for a few minutes but fail when required to run for hours. Problems such as overheating or vibration are likely to be revealed only by a suitably long test.
— Power failure tests should be included for entire plant areas, and fuse failures simulated in order to cause partial power failure (partial failure can be worse than complete failure since some equipment may still operate even though equipment interfaces are unavailable). These tests should also include supply fluctuations (e.g. voltage fluctuations) where equipment behaviour is sensitive to such fluctuations.

— Software controlled systems should be subjected to special tests and procedures. These should cover as wide a range of operating circumstances as possible, since the possibility of design errors is much greater for software systems (they tend to be much more complex than hardware systems) and only extensive testing (or analysis and verification procedures) can be expected to reveal faults and failures before operation. Procedures should be devised and approved to cater for configuration control, temporary and permanent modifications, access control and software security to prevent unauthorized changes, hacking and introduction of viruses. Temporary modifications may be needed where contrived situations are deliberately set up within the software to facilitate testing of specific functions. These should only be introduced when unavoidable and a log maintained to show their status. Associated procedures should not allow the removal of changes from temporarily modified software, but instead should require the modified version to be discarded and the original software reloaded to avoid potential for error introduction during the modification removal stage.
— Where data highways are used (generally but not always associated with software systems), data overload tests should be carried out to verify capacity and time response of the receiving systems during periods of high activity. There should be a comfortable margin between receiving system capacity and maximum expected load.
— Validation of periodic proof tests should be carried out, both to establish effectiveness of the proposed procedures (possibly by inclusion of seeded faults where there are doubts), and to confirm any assumptions that are implicit in the proof tests themselves. For example, it is often impracticable to permit a function to be tested during plant operation, and a substitute test may be devised to check that a relay contact is made by inducing a short circuit between two terminal points. In such cases, the assumption is that the terminal points are appropriate, and the proof test validation procedure should establish that the assumption is correct beyond reasonable doubt.
— Records of temporary modifications should be maintained and procedures implemented to ensure that systems are reinstated correctly.
— Where there are variable set points for control, protection or warning functions, tests should be carried out to verify correct function for values across the full range.
— Sensitive systems should be tested for susceptibility to electromagnetic interference, including electrostatic discharge. This applies especially where high power electrical equipment or cables are near such systems.
— Where operators are required to carry out diagnostic procedures after malfunction, commissioning tests should be included to validate expected plant behaviour during such procedures.
— If a plant simulator is to be used to assist in carrying out control system tests, and if its accuracy is depended upon to any extent for safety equipment, its fidelity should be established using specially designed validation procedures.
— Calibration procedures for temporary and permanent measuring instruments should be shown to be comprehensive and reliable, with auditable trails to identify substandard instruments, and effective procedures for identification, certification, use control and recalibration at appropriate intervals.

The IAEA has produced a number of publications related to I&C upgrades for power uprates or for conversions to digital or hybrid analogue–digital systems [125–129]. In these publications, certain testing and commissioning steps are described, including:

— System integration testing of the various project specific (engineered) applications with the specified platform configuration, including parameterizing and preliminary tuning of the applications together with the platform.
— Use of FATs to ensure that HSIs comply with all requirements defined in contract documents prior to shipment to the plant.
— Where possible, use of the plant training simulator after the FAT with a stand-alone copy of the new I&C equipment as a test bed for validation under real time conditions (i.e. together with the plant model), and for operator and maintenance staff training prior to implementation in the plant. The simulator can also be useful for future system modifications as an effective tool for validation, licensing and training.
— Use of SATs to verify that all HSIs operate properly in the field environment and do not suffer damage during shipment. SATs are done without impact on the process (no connection to valves, pumps etc.). They can also be designed to complement the FATs (to confirm specific interfaces with plant equipment, etc.). A list

of acceptance criteria should be prepared by the supplier, and approved by the buyer, according to contract requirements, considering results of the FAT. At a minimum, testing needs to include the following:
  - Verification of proper power supply at all test points;
  - Verification of system performance on a loss of power;
  - Verification of all functions, including displays, communication protocols and data transmission;
  - Verification of proper interface, monitoring and control functions.
- Parallel operation of the old and new systems as required to verify proper operation of the new system before it is commissioned for operation in the plant.
- Final commissioning tests for functionality of the system connected to the I&C and process equipment. This includes final operational testing, and validation of long term performance of HSIs. A sufficient period of time must be allocated for the commissioning test to validate the HSI performance in the entire circuit, from the devices in the main control room (MCR) to the actuators in the field.

Figure 12 contains a model showing how commissioning, SAT, FAT and system integration testing are linked.

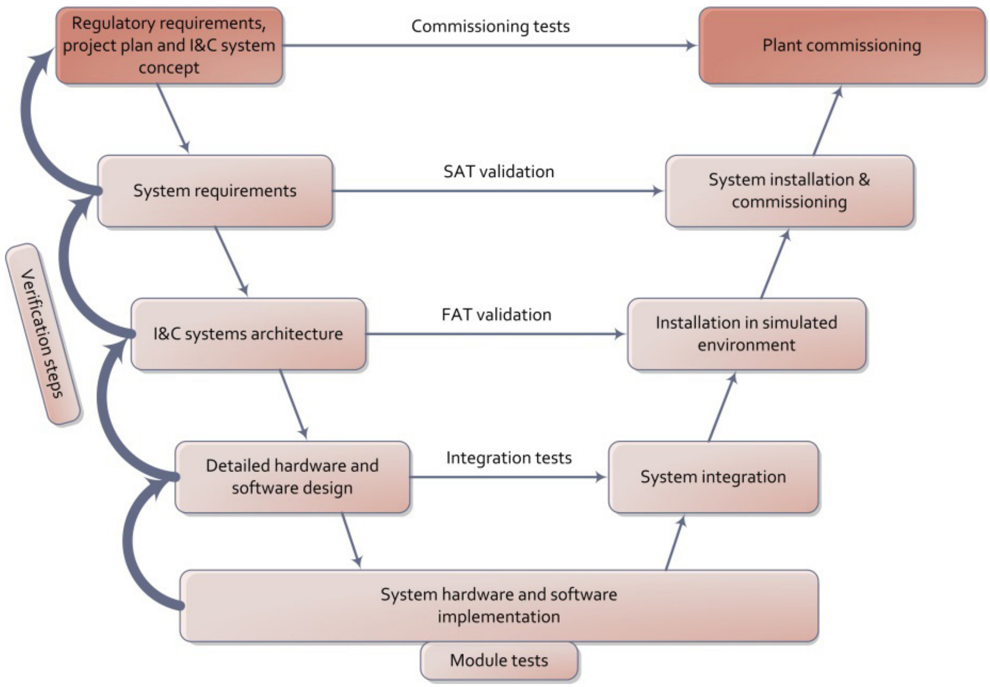

FIG. 12. V-model of I&C system life cycle, interpretation based on the IEC and IEEE standards (adapted from [130]).

4.5.2.7. Commissioning phase testing

Commissioning phase testing (overall integrated testing) is carried out following a process similar to that for system commissioning (functional testing). Particularly important elements include the following:

- Planning and preparation for the testing, including a check for required documentation, staffing and logistics;
- Careful, day-to-day schedule monitoring, with continuous evaluation of satisfactory completion of activities;
- A formal review before starting, to confirm plant and environment conditions and assess whether prerequisites are met.

Lessons learned suggest that the following are beneficial:

- Set-up of a commissioning committee as described in Section 5.3 for overall coordination and management;

— Establishment and use of a phase commissioning programme to provide a road map for managing test and other activities during the phase or subphase, and to assess plant conditions for starting and ending the phase or subphase.

To comply with these objectives, checks typically include verifying that the following items for each phase are documented and available:

— Prerequisites to start the phase/subphase.
— Precautions for the phase/subphase, including particular measures and temporary devices to be applied to secure the phase, mitigate risks, manage critical steps and reach test success.
— Initial status of the area concerned and the systems required for readiness assessment.
— Installation completion status, system configuration, safety measures, required authorization.
— Complete documentation package including test procedures.
— Detailed instructions to manage the tests during the phase.
— Specific instructions to reach initial status.
— Tasks to start the plant based on operation procedures. Detailed instructions of the phase commissioning programme fix the test sequence and interfaces between tests and operation activities during the phase through exact document references (test procedure and operating documents to be applied).
— Specific instructions to recover operating configuration after the test.
— Sequencing of phase activities including warnings for key milestones and evolution of the plant parameters during the phase/subphase.

4.5.2.8. Module commissioning

In recent and new types of construction, large modules are increasingly constructed in a module assembly shop or yard and lifted into place in their final location within the NPP. Typical module types are structural and commodity modules (Fig. 13). Structural modules are large (approximately 1000 t), and are typically duplex stainless steel forms with tanks and piping included. Commodity modules are large equipment skids containing piping, controls, tanks and other equipment.

Experience to date has been that modules are not always fully outfitted at time of the module lift (owing to the design not being 100% complete or for other reasons). For these, only the structural integrity of the modules would typically be verified prior to the lift. For commodity modules, some more intrusive checks are possible (e.g. visual and manual functional checks such as turning of valves). As experience is gained by construction organizations, or for later builds of similar designs, the amount of module commissioning can be expected to increase. However, commissioning steps undertaken prior to a lift must be assessed to determine whether they can be accepted as proof of valid commissioning completion post-lift, as the lifting process itself might induce changes. Even if not acceptable as commissioning evidence, such testing may be prudent to minimize potential for schedule delays later in the NPP project. Such trade-offs and assessments are like those typically made for factory versus on-site testing.

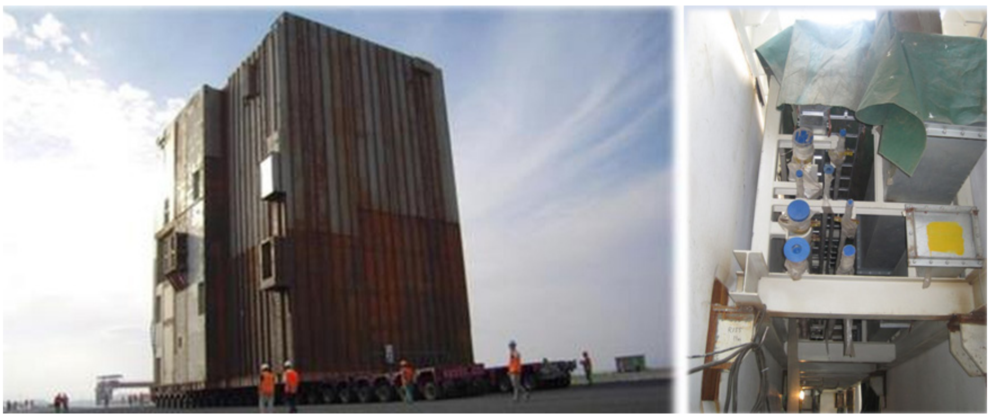

FIG. 13. Structural module (left) and commodity module (right).

Turnover from construction to commissioning for systems installed on modules is typically done by individual system (that is, once entire systems are assembled on the site, including the on-module and off-module portions).

4.5.2.9. Direct, advance and parallel commissioning

For renovation and retrofit projects, commissioning can be performed in a direct, advance or parallel manner [131]. Direct commissioning is the traditional approach of stopping a plant or system to install and test the new equipment. Advance commissioning is the commissioning of the new equipment prior to installation. Parallel commissioning is the commissioning of the new unit in its operating position, while the old unit is still operational. For some equipment, the techniques can be combined in a sequential manner.

Although it is the most common approach, there is a high level of downtime in direct commissioning as the whole system cannot be operated until the new unit is electrically, mechanically and operationally tested. There is also the risk of having to reinstall the old unit if there are significant complications at any phase of the commissioning process.

Advance commissioning requires simulation of all systems that interact with the new equipment, often in a factory setting. Full functionality of the unit cannot be proven as the system is being simulated by external means, which will always be an approximation of reality. The most common type of advance commissioning is the development of model systems for conceptual designs which simulate the operation of both the system and the new unit. The main drawback of advance commissioning is that the process is only simulated, so there is still the potential that the unit can fail when installed into its operational environment.

Parallel commissioning is the testing of the new system in parallel to the operating system. Parallel commissioning allows for the new equipment to be tested under full operational conditions, with low risk of significant process interruptions due to the added redundancy of the old system being present in an operational capacity. However it also has the highest cost, as it requires duplicate hardware systems and additional structural space. The main risk associated with parallel commissioning is the integration between the two systems. Often there is some type of switching or merging component in these systems which may require minor process stoppage for installation. Parallel commissioning is often completed when it is critical that the process not be stopped for any extended period of time. It often lends itself to processes with few interactions between new equipment operation and the rest of the process. Parallel commissioning may be useful in a nuclear environment for replacement of ageing or obsolete equipment when operational continuity is required and when timing constraints are tight (such as during a unit outage).

4.5.3. Review and acceptance of test results

Following completion of testing, test results are analysed and accepted according to the following principles:

— An analysis of tests results is performed and a statement regarding their acceptability is issued by the commissioning organization. Configurations, assumptions, inputs and test results are reviewed in light of acceptance criteria and the review documented in a test report.
— Test reports are jointly accepted/approved by the owner/operator and the commissioning organization. Certain reports for safety relevant tests and systems may also be subject to regulatory authority review.
— Remaining deficiencies, reservations or reasons for test rejection are documented. Actions to address all issues are assigned as required.

Protocols should be put in place to schedule and otherwise facilitate reviews by the owner/operator or the regulator as required. This can avoid rework or repeat testing during commissioning, which can impact schedules.

During nuclear commissioning, from fuel loading to power level increases up to full power, test reports supporting completion of each commissioning stage are prepared. These phase reports summarize all commissioning activities of different commissioning groups supporting completion of a particular stage.

The following sections describe common practical arrangements that complement the test validation process.

4.5.3.1. Test result evaluation and approval

Results of commissioning tests must be compared to the design parameters. They will be accepted if they meet the defined acceptance criteria. Results are compiled in test/commissioning reports. These are reviewed by engineering staff experienced in the relevant discipline, and typically by the operating organization. Following commissioning staff review, a common good practice is to schedule an 'available for service' (AFS) meeting to formally review and challenge commissioning results and the acceptability of declaring a system or subsystem commissioned and in-service. Such meetings are typically associated with the turnover of the system or subsystem to the operating organization (see Section 4.7 and Appendix VIII).

To save time, draft test reports and AFS meeting preparations can be initiated before or during the commissioning testing. A special commissioning group for test evaluation and documentation can also save time.

Test certificates or similar records certify that testing has been completed in accordance with the procedure. They will document any deviations from procedures and any justifications or remedial actions.

In some cases, resolution of deviations or non-conformances encountered during commissioning may require design, operational or safety documentation to be updated. See Section 4.9 for further details.

At the end of each commissioning phase following completion of functional system tests, reactor performance, reliability and safety are typically reviewed as a whole. Feedback or design change proposals should be raised and submitted to the interfacing disciplines for evaluation and approval. Particular attention should be paid to cascading effects resulting from changes to control room hardware, plant software or operating procedures.

4.5.3.2. Overall test phase completion

Once all tests of a commissioning phase are completed successfully, a phase completion certificate is produced and approved by plant management or the commissioning committee before the next phase is initiated. Regulator review may also be required to proceed.

To fulfil this requirement, good practice applied in several countries is to generate specific test reports at each stage of commissioning and perform a review of stage completion to ascertain that all objectives and regulatory requirements have been fulfilled. These stage reports present test results to demonstrate compliance with test acceptance criteria and to get authorization from the owner and regulator if it is required to start the next stage. They also record and document key commissioning events. Deviations or changes as well as unexpected events, if any, should be justified and documented to support test and stage acceptance. Remaining items, if any, will be reported in the list of open items with milestones identified for their closure. Proceeding from one stage to the next is not permitted until commissioning test results have been evaluated. For this purpose, a review meeting is organized after each phase with the owner/operator and the regulator (if required) to review the stage report.

Moreover, a review of test results and system/plant status is necessary to confirm that all phase prerequisites are met before proceeding to the subsequent overall test phase/subphase.

Preoperational overall tests are mainly to assess the starting configurations of the cold and hot functional tests. The typical nuclear commissioning phases are fuel loading, first criticality authorization and selected power increases (hold points).

4.6. NON-COMMISSIONABLE ATTRIBUTES

System attributes need to be confirmed to ensure that design requirements are met. In certain cases, only some of these attributes can be confirmed by traditional commissioning functional testing. Non-commissionable attributes can be associated with passive components requiring environmental or equipment qualification (e.g. conduit or enclosure seals, splices), passive fire protection system components (e.g. fire barriers, sprinkler fusible links), and items required for seismic qualification (e.g. snubbers, in-line anchors and penetrations, flexible building joints).

For these cases some jurisdictions have incorporated enhanced processes to validate such attributes into their modification and commissioning processes, including the following:

— Formal assessment of whether the system is fully commissionable or not (including all its critical attributes).
— When found not fully commissionable:

- ◦ Documentation and assessment of critical design attributes by a party independent from the design team (e.g. a separate design verifier or a third party);
- ◦ Assignment of a specific individual responsible for ensuring field installation conforms to the defined critical design attributes;
- ◦ Enhanced oversight of design and turnover processes associated with the non-commissionable attributes in a design.

An example of a utility's implementation of these enhanced processes is included at the end of Appendix VI.

4.7. TURNOVER FROM COMMISSIONING TO OPERATIONS

Following completion of commissioning activities, SSCs are turned over to the operating organization. Operations staff will have participated in system tests in support of commissioning and will already be performing system operation and surveillance activities in accordance with the preliminary operating manuals and specific instructions from commissioning.

Operations staff will need to be available for round the clock shift coverage following turnover from commissioning to operations. This typically first occurs following first plant electrical system energization.

If a system is required to operate during construction, or when the system is included in a commissioning phase, the operating organization will take it over in a phased manner as soon as commissioning tests have proven it can be operated continuously, either entirely or partially.

At fuel loading, there will be a turnover of the whole plant to operations, called a turnover for nuclear operation (Section 4.7.2).

Final owner acceptance for the plant is carried out at the end of commissioning (Section 4.8).

4.7.1. Turnover for temporary operation

When a system or a group of systems has been commissioned and can run continuously, or when a system that has been commissioned must be operated as part of an overall plant test phase, it must be turned over to the operating organization for temporary operation.

Temporary operation of systems for commissioning purposes can last a while. Consequently, on-shift monitoring and surveillance by operations staff is required. Usually, this turnover also covers the responsibility for routine maintenance of the equipment transferred.

As part of turnover of a system for temporary operation:

- — The operating organization takes charge of all operating and monitoring activities for the systems that have been turned over.
- — Any work or testing required on SSCs turned over to operations is done with a formal work or test permit authorized by the operating organization.
- — System test conditions are directed by commissioning staff and managed by operations staff. In practice this means that the operating organization carries out the test following instructions prepared by commissioning.

4.7.2. Turnover for nuclear operation

At fuel loading, the operating organization takes over and the plant is placed in 'temporary nuclear operation' status. The commissioning organization remains responsible for the preparation and performance of the remaining commissioning tests. The NPP officially becomes a 'nuclear' facility and additional safety and licensing provisions need to be implemented. The operating organization has full responsibility for nuclear and radiation safety management, and therefore needs to have the processes in place to ensure that it can assume those responsibilities. For NPPs with natural uranium and heavy water (e.g. CANDU reactors), the equivalent key date is the date on which the primary circuit is filled with heavy water.

In most countries, an NPP is considered to be in operation when the first nuclear fuel is loaded into the reactor. Loading of the reactor may begin after the unit has been granted an operating licence and the regulator has accepted the fuel loading application. Typically, this requires the owner/operator to provide a report on the reactor and fuel behaviour during the initial operating period. The regulator typically carries out an inspection in accordance with local regulations, leading to the required core load start authorization.

Before receiving nuclear fuel at the site, the following prerequisites are typically required:

— Trained and qualified staff are available and assigned responsibility for nuclear safety and fuel acceptance, handling, transportation, storage and accounting.
— Documentation on nuclear safety provisions is developed and approved.
— Processes for nuclear fuel handling, including radiological protection; decontamination; and fuel acceptance, transportation, storage and accounting, are developed and available.
— Fuel transportation, handling and storage equipment is tested and ready for final commissioning tests (i.e. with 'real' fuel).
— Controlled access and security provisions are set up for areas where nuclear fuel is handled and stored, and for the NPP as a whole.
— Emergency planning and response personnel and processes are in place.
— Event reporting and corrective action processes are in place.

Typical specific requirements surrounding fuel storage, transportation and loading processes include the following:

— Nuclear fuel is only stored or temporarily placed in specially dedicated locations as determined by design.
— Access to places where nuclear fuel is stored or temporarily located is restricted.
— Lifting or hoisting objects over nuclear fuel (other than fuel handling equipment) is restricted.
— Fuel transportation routes are as straight and simple as possible to minimize the possibility of fuel damage.
— Fuel transport containers are anchored to transport vehicles to prevent them from falling, even in the event of a design basis earthquake.
— During transportation, storage and loading of nuclear fuel, safeguards provisions for control of and accounting for all fuel assemblies are provided at all times. Nuclear fuel safety requirements are met at all times and procedures are developed for nuclear fuel transportation and storage, including during the period approaching first criticality.

Regulatory approval is obtained before first fuel loading or filling of the system with D_2O (for PHWRs) begins. Systems or equipment needed to support safe reactor operation during and following fuelling will need to have been commissioned.

Before turnover to the operating organization, system operation and surveillance is carried out in accordance with the operating and testing manuals and following any additional instructions from commissioning staff in agreement with operations staff. At fuel loading, the operating organization takes charge of all operating and monitoring activities for the whole plant, including routine maintenance of components and systems. Nuclear safety requirements must be enforced at all times during commissioning, operation and maintenance. This may include the following aspects:

— Safety related tests and general commissioning test programmes should be developed and conducted in accordance with national regulations. These test programmes should contain specific detailed safety requirements as dictated by the design organization and in accordance with national regulations and the design of the plant.
— Operation and maintenance of safety related equipment and systems within the safety boundary should always be performed in accordance with the operating technical specifications.
— Periodic testing may also be conducted as required.

Turnover packages and related items provided by the commissioning organization to the operating organization at this time include the following:

— Turnover open item list (see Section 4.11.3);

— System related documents such as operational flow sheets (identifying scope of turnover and level of completion), operational process and instrumentation diagrams and electrical drawings, operating manuals, emergency preparedness documents and testing procedures (see Section 4.2.2.10);
— Copy of outstanding non-conformance reports and field change records;
— Startup test results;
— Specific construction acceptance tests/flushing/preoperation summary sheet and event records;
— Preventive maintenance records, special maintenance records, etc.;
— Sufficient training for operations staff, including lessons learned during commissioning of systems and equipment;
— Test reports (commissioning reports for systems and equipment containing baseline data for future reference);
— Descriptions of modifications to system equipment or control logic, and any temporary procedures adopted during commissioning;
— Any segregation and isolation requirements between systems already in operation and those being commissioned.

A formal checklist such as that provided in Appendix IV can be created to facilitate the handover to the operating organization. As described in Section 4.5.3.1, a formal AFS meeting is often held in which system status and commissioning results are jointly reviewed by commissioning and operating organization personnel. If the system is in an acceptable condition, then formal system transfer occurs following the meeting. After turnover to the operating organization, completion of remaining commissioning activities for partially commissioned systems is normally carried out by the commissioning group under the control of operations staff. Any work on SSCs already turned over to operations is to be authorized by the operating organization. Some further details on conduct of AFS meetings are included in Appendix VIII.

4.7.3. Area and room turnover

If they have not been turned over previously (as described in Section 4.4.2), buildings, structures or rooms must be formally turned over to operations before the final plant acceptance.

4.8. FINAL PLANT ACCEPTANCE

Successful completion of core physics tests, power ascension tests and other plant acceptance tests may take six months or more from initial core loading and removal of the shutdown guarantee. During this initial period of operation, it is normal practice to plan a short outage (e.g. one month) or multiple short outages to clear all items still unresolved.

During the initial operation period, system and plant acceptance tests are carried out. These may be required by contract or by applicable codes and regulations. Such tests may include verification of generator output and other performance capability, plant thermal performance, steam moisture content and general system reliability for a contractually agreed time. Tests are typically performed at 100% power and steady state conditions.

Following completion of this test period (and associated outage), the plant is formally turned over to the owner for final acceptance.

4.9. NON-CONFORMANCE MANAGEMENT, REWORK AND TROUBLESHOOTING

4.9.1. Non-conformance process

Non-conformance can be defined as “a deficiency in characteristics, documentation or procedure, which renders the Quality of an Item unacceptable or indeterminate” [132]. As was described in Section 2.4, commissioning is intended to ensure conformance, which means that SSCs have been properly designed and constructed, and that their performance is in accordance with the design intent and safety analysis.

Actions necessary to resolve non-conformances depends on the nature of test results. Such actions may include changes to the design of equipment, systems or structures; elimination of defects; or changes to the tests, test acceptance criteria (if justifiable) or operating procedures.

As stated in para. 6.15 of SSR-2/2 (Rev. 1) [8]: “Resolutions to correct differences from the initial design and non-conformances shall be documented.” This allows for future auditing of actions and understanding of the issue and corrective actions taken.

The operating organization should establish a process for dealing with these situations in accordance with national practice. Before turnover, a similar process (preferably the same process) should be established within the commissioning organization. An example of possible actions is shown in Fig. 14.

Where unexpected results are encountered, there can be a difference of opinion between the operating or commissioning organization and the regulatory body as to the significance or approach to be taken to resolve the issue. It is useful to have a predefined method for obtaining a resolution to these discrepancies — typically escalation of the issue to higher levels of management in each organization. The significance of the issue dictates the timeline for escalation.

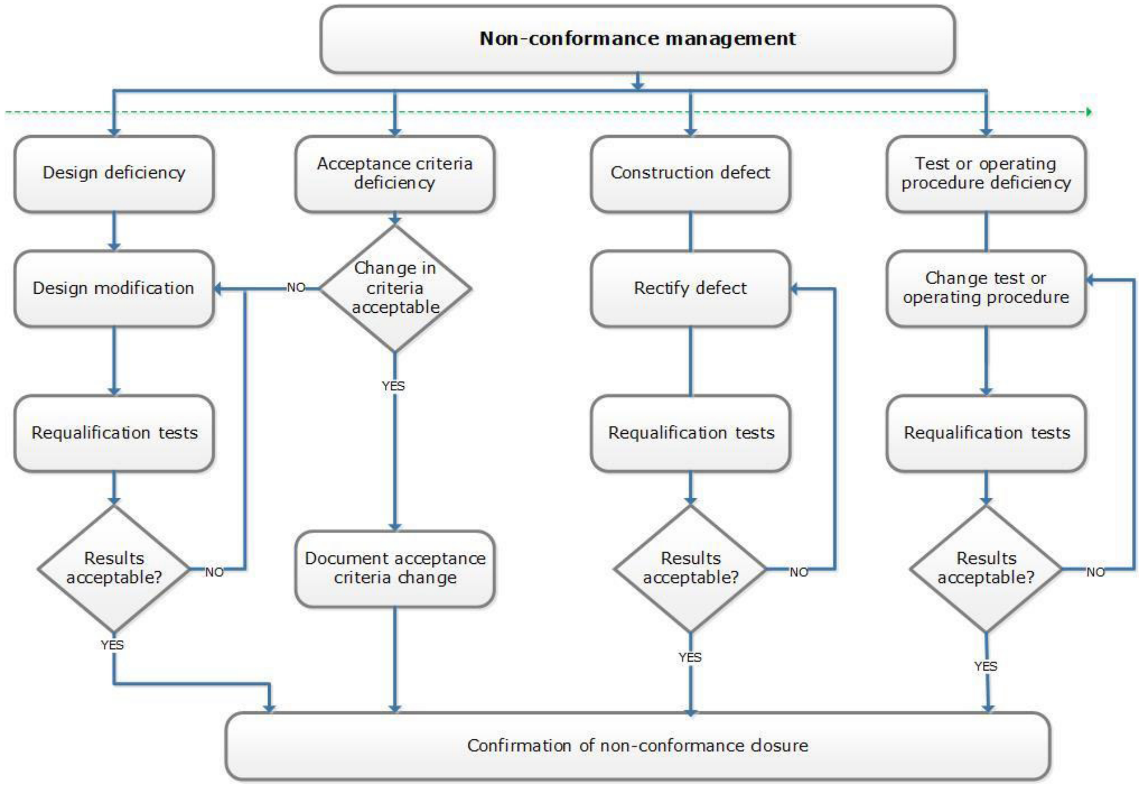

FIG. 14. Possible actions in case of non-conformances.

4.9.2. Test reviews

Modifications to the facility can occur at any time during the commissioning process. These can be due to parallel construction or commissioning activities, open item completion, design changes, correction of non-conformances or preventive or corrective maintenance. Tests that were planned or written a while before they were due to occur, or were stopped or delayed, need to be assessed and revalidated based on potentially changed conditions prior to their execution. Upon review, tests that have already been completed may be invalidated or may need to be repeated. Test procedures or commissioning programme documents may need to be revised to reflect the current situation.

Requirements for test reviews (e.g. time frames or conditions when such reviews are required) should be documented in commissioning management system documents.

Following such a review, the applicable test is released for field use at the appropriate step or flagged or quarantined as needing revision. An open item to record any needed repeat test or needed changes to the test, operating procedures or periodic test procedures is added to the system's open item list.

4.9.3. Troubleshooting

Commissioning testing invariably involves some degree of troubleshooting, which is a logical, systematic search for the source of a commissioning problem so that the applicable system can be made to function as per its requirements. Unexpected results may have been observed during commissioning. These may include equipment malfunctions; unexpected responses from equipment or systems (wrong alarm responses, devices not operating or not operating as expected, etc.); plant, equipment, or personnel being placed in an unsafe condition; procedure steps being incorrect, unclear or inconsistent; or acceptance criteria not being met.

In such cases, commissioning personnel should stop the activity, place the equipment and the job site in a safe condition, and contact the responsible supervisor and the operating organization to resolve the issue. Where it is determined that the procedure cannot be performed as written, solutions may require correction of installation deficiencies, repair or replacement of equipment or components, design changes, or changes or corrections to the commissioning procedure. Assessments of any changes to testing typically need to confirm that the changes do not fall outside the range of assumptions in the safety analysis, do not invalidate the results of any previous testing, and do not impact any further tests in terms of their scope, objectives and sequence.

For efficiency, it is preferable that commissioning test procedures incorporate some flexibility to allow for limited troubleshooting of anticipated potential issues. This requires some skill on behalf of the procedure author in the ability to anticipate potential issues and document specific solutions to them using 'IF–THEN' clauses in the approved procedures (e.g. IF acceptance criterion X is not met THEN do Y).

When situations arise where troubleshooting is needed outside of the written commissioning procedure, the procedure is typically revised using the appropriate process. Alternately, some jurisdictions have developed a maintenance troubleshooting process to formalize their approach to troubleshooting. Such a process allows the troubleshooters to develop a step by step troubleshooting plan in conjunction with engineering staff to investigate the specific issue within specific boundary conditions. Once this troubleshooting procedure has been completed and the situation corrected, the original commissioning procedure is restarted at an appropriate point.

4.10. ASSESSMENT, OVERSIGHT AND CONTINUOUS IMPROVEMENT

Any management system should have processes in place for assessment (performance monitoring), independent oversight and continuous improvement for all involved parties, including contractors.

4.10.1. Assessment of commissioning activities

Assessment of commissioning activities can occur from the perspectives of quality, schedule and cost. Organizations typically develop performance measures related to these for large projects, and ideally they will continually scrutinize their metric sets for opportunities for improvement and insight. Individual subtier organizations should each have their own set of measures for assessment and improvement purposes.

Quality measures can include measures of non-conformances detected, industrial safety incident numbers or rates, rework metrics (by discipline or system), commissioning or operating errors or breakthrough events, unapproved modifications, instances of procedural or regulatory non-compliance, and others.

Schedule metrics can use calculations of deliverable based earned value compared to a baseline schedule. The baseline schedule is populated with specific items to be completed by a certain date, and the schedule is updated with those actually completed on that date. Such metrics can be developed for individual work groups or types of activities (e.g. design package issuance, construction turnovers completed, instrument loops commissioned, commissioning turnovers completed, regulatory approval letters received, systems or equipment items turned over).

In traditional earned value management, a schedule variance (which is defined as the earned value of the schedule minus its planned value) of 0 or a schedule performance index (defined as the earned value of the schedule divided by its planned value) of 1 indicates that a project is exactly on schedule.

Some effort is required to populate the earned value plan into the baseline schedule, as the number of deliverables may not be fully clear, or they may not be easily allocated to particular completion dates. However, caution should be taken with incorporating 'spent to date' measurements as a proxy for actual deliverables (work completed) in earned value calculations. Such values may not be reflective of work actually done; the project may be spending money with little or no actual field progress.

Detailed records are kept of the costs of projects and their commissioning activities. Cost metrics are similar to schedule metrics in that a baseline cost estimate versus time should be compared with actual field spending. Earned value techniques should be used for monitoring progress, meaning that only objective completion of a particular deliverable should allow that scheduled activity to be shown as 'earned'. Cost escalation metrics are another type of cost metric that can be useful. These metrics, which look backwards once projects are completed, track actual project costs divided by budgeted costs.

4.10.2. Independent oversight

Independent oversight of commissioning should be planned. This is typically performed by a separate organization with NPP commissioning or operating expertise that reports directly to a high level executive. Such an organization should be independent of the activities being performed. It carries out independent audits, on behalf of the executive, related to commissioning activities. A useful audit that can be performed early on or just prior to commissioning is one designed to confirm that commissioning management system requirements as described in national regulations and/or in IAEA standards are being met in practice.

Outside organizations such as the IAEA, World Association of Nuclear Operators (WANO), or Institute of Nuclear Power Operations (INPO) can provide industry experts to perform assessments on aspects of the commissioning process. The IAEA's Operational Safety Review Team (OSART) process [133], for example, provides an assessment of commissioning activities. Ad hoc groups of executives or industry peers can also provide independent reviews and recommendations.

4.10.3. Continuous improvement

A key requirement for any process or management system is to have continuous improvement processes in place. Figure 15 shows a management driven seven step cyclic approach for improvement.

With respect to commissioning, input for continuous improvement activities should be taken from observed non-conformances (Section 4.9), assessments or performance metrics (Section 4.10.1), independent oversight audits (Section 4.10.2) and external operating experience (Section 6.2 and other sources). Typically, NPPs in the commissioning phase have an active corrective action programme that logs events, grades them as to severity, performs trending, and initiates interim or corrective actions and/or further analysis as required. Senior management needs to actively support and be involved with such programmes and use them to drive improvement activities.

4.11. OTHER CONSIDERATIONS

4.11.1. Refurbishment, uprating and restart project approaches

In contrast to a newly constructed reactor, SSCs in an NPP undergoing refurbishment, uprating or restart reside in various states of lay-up, shutdown or even operation. For these, a normal suite of commissioning tests applied to new facilities is not applicable in its entirety.

Commissioning activities for plant refurbishment or restart are commensurate to the extent of repairs, replacements and/or modifications performed. Integrated testing is conducted based on the design alterations or safety analysis assumptions that are impacted. In any case, sufficient tests need to be conducted to provide a high level of assurance that all systems meet safety requirements. This may include a selection of integrated system tests, up to and including full power tests.

As described in the sections that follow, the extent of commissioning depends on the state the impacted system was in during the refurbishment period.

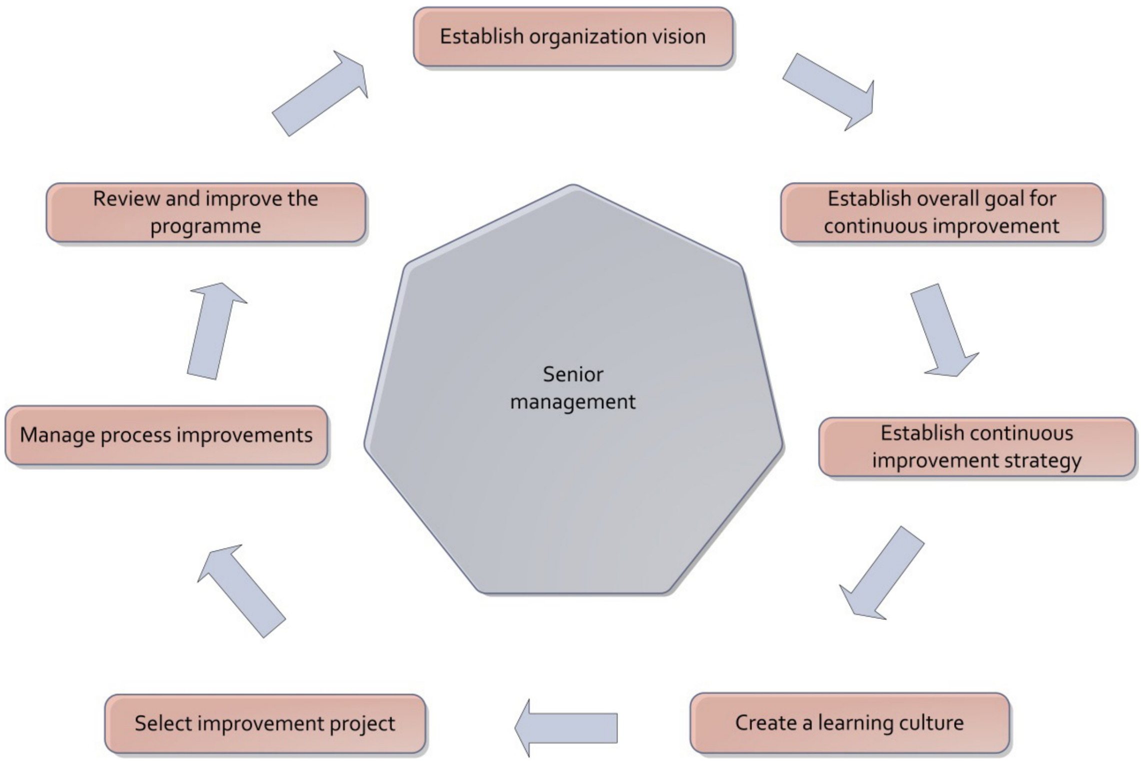

FIG. 15. Structured approach to a continuous improvement programme (adapted from [134]).

(a) SSCs in normal operation

These are SSCs that remained in normal operation, with continued system health monitoring and routine maintenance programme activities. Commissioning activities for these SSCs will be limited to checks and tests required to verify that they can safely return to normal service, possibly with increased or different operational loads.

(b) SSCs shut down

These are the SSCs that were shut down and placed in a laid-up state. This includes SSCs that may have been disconnected or dismantled to provide access to perform work during the refurbishment. Commissioning activities for these SSCs will be commensurate with SSC specific conditions, to ensure that they are operable and that applicable design and safety analysis assumptions are still met.

(c) New or modified SSCs

These are newly installed systems or existing systems that underwent significant repairs, replacements or modifications. Commissioning will be performed to confirm that these SSCs as reintegrated into the plant perform in accordance with design specifications. This commissioning is similar to what is done for a newly constructed NPP.

4.11.2. Maintenance during commissioning

Nuclear facilities need to be adequately monitored and maintained, even during the construction and commissioning period. This protects equipment from degradation until normal maintenance processes are in place. Maintenance responsibilities during commissioning need to be adequately described and documented so as to be clear to all parties involved. Following equipment startup, the operating organization personnel who will be responsible for equipment maintenance in the long term usually take over maintenance duties under commissioning organization authorization. However, alternate arrangements are possible.

Historical records of maintenance during the commissioning phase are needed from the time of initial equipment energization of each plant system. Provision should be made to transfer these records to the operating organization at the time of the system turnover. Record keeping using the enterprise database system that will be used for long term maintenance can ease this transition.

Recommendations and guidance on maintenance activities are provided in IAEA Safety Standards Series No. NS-G-2.6, Maintenance, Surveillance, and In-Service Inspection in Nuclear Power Plants [115].

4.11.3. Open item list management

An open item list (also called a punch list) is an exhaustive list of all remaining deficiencies and reservations related to a system. It is initiated at the time of the turnover of a system to commissioning. All open items need to be closed before the plant can reach its final completion status. The list is a key tool for managing system progress through the commissioning period, up until the provisional takeover of the unit by the owner/operator.

Open items should not constitute a reason for the owner/operator to block the progress of commissioning, unless such work has an impact on test performance or on test results.

Each item is recorded with a milestone closure date. The list is managed by commissioning staff, and the owner/operator may check the list at any time.

The list is updated until commissioning ends, as needed, as reservations and issues related to construction, commissioning, operation and maintenance are cleared and new defects or reservations for the system are raised.

A review of the open item list is regularly carried out before system tests, at selected commissioning milestones, at the start of a new commissioning phase and at the time of system turnover to operations. These reviews are to ensure that remaining items will not affect test performance and results, or adversely affect plant operation. Where adverse impacts are possible, completion of the open item is expedited or compensatory measures taken.

Sample open item lists are included as part of the turnover checklists in Appendices IV and V.

5. HUMAN RESOURCES AND ORGANIZATIONAL MODELS

5.1. GENERAL

Commissioning should not be an isolated activity. It is typically led by a commissioning management group, and is jointly performed with many organizations, including organizations specializing in construction, operations, maintenance and design; manufacturers; technical support organizations (scientific and research organizations, external commissioning experts, etc.) and the NPP vendor. The commissioning management group should produce a convenient and practical working plan and work processes that allow an optimum utilization of the available resources to adequately meet all safety and performance objectives.

Organizational arrangements and the division of responsibilities among the participating organizations depend on the project's industrial scheme, on contractual and organizational models chosen by the owner for commissioning, and on the plant physical size and design. The composition of the group may be influenced by availability and experience of personnel performing specialized functions.

Nevertheless, commissioning organizational models in any type of contractual approach are normally based on the owner/operator being responsible for commissioning planning. Additionally, all functions of the operating organization are to be performed at the appropriate stages during commissioning, to ensure that the operating organization is prepared for the operational phase of the plant. Task sharing in commissioning activities should be determined by the owner, even for turnkey contracts. If the owner decides to subcontract commissioning activities to another organization, it should be made clear that ultimate responsibility for commissioning and for plant safety remains with the owner.

Specific responsibilities of organizations involved in NPP projects and their commissioning are determined according to national practice, and are reflected in relevant commissioning management system documents and contracts. As shown in Fig. 16, these responsibilities will evolve over time as the specific project moves from being construction-led to being commissioning-led, and finally to being operations-led.

The usual arrangement during the main commissioning period is to have commissioning led by a commissioning management group. This group interfaces with personnel from other organizations involved in commissioning, including the commissioning organization itself, operations, subcontractors involved in commissioning, design (including equipment designers), equipment manufacturers, construction and erecting organizations, quality surveillance inspectors, external organizations providing scientific support and expertise, and the regulator.

International experience has shown that plants where operating staff were not intimately involved in commissioning have suffered higher incidences of unplanned events during the early years of operation, when compared to those that had operating staff involvement.

The following sections present different approaches and models for organizing commissioning and discuss sizing of resources and means, and training and qualification of staff involved in commissioning, based on experience feedback and lessons learned.

Appendix I presents three typical organizational models based on a compilation of approaches adopted in the past. Appendix III contains a typical matrix showing commissioning related responsibilities for the commissioning and operating organizations.

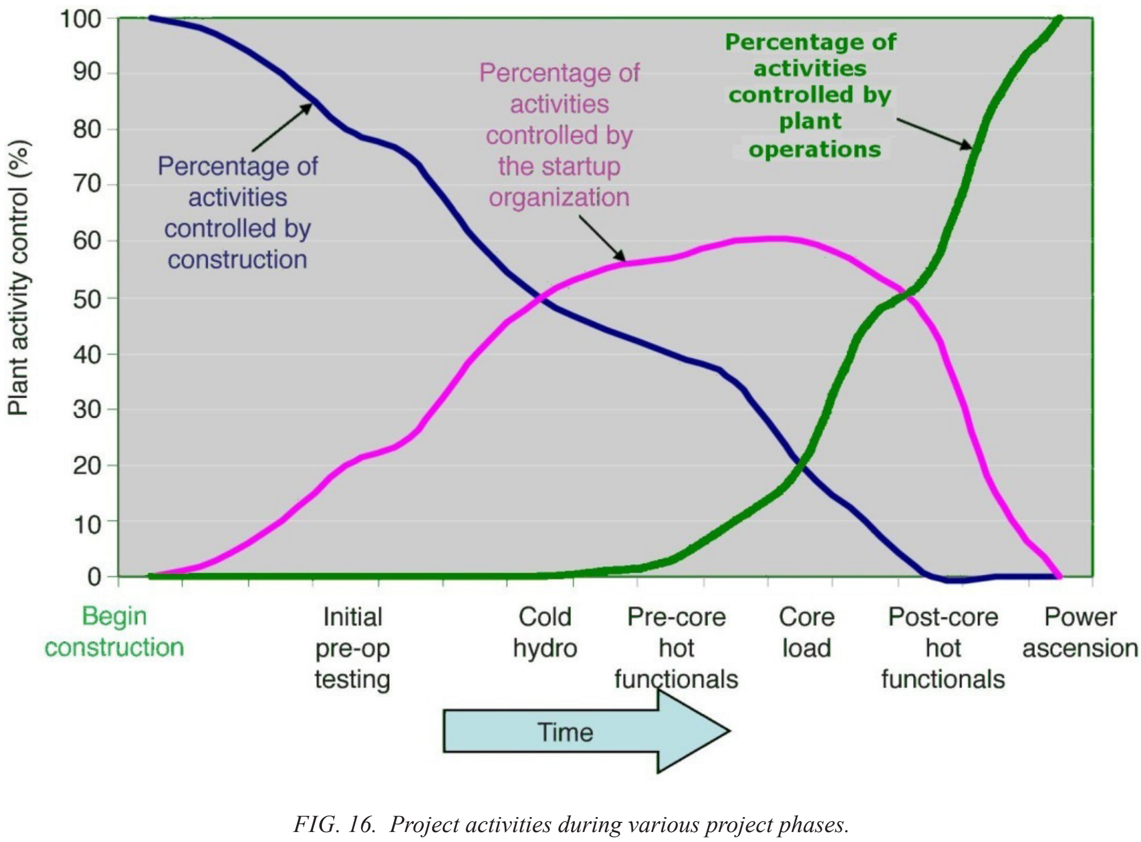

FIG. 16. Project activities during various project phases.

5.2. COMMISSIONING ORGANIZATION APPROACHES

Detailed organization charts, job descriptions and responsibilities of the groups involved depend on the industrial make-up of the project and on the contractual models for the project's construction, commissioning and operational phases. The most common contract models are the following:

— Turnkey contract for the whole plant, with owner supervision. These can include build–own–operate or build–operate–transfer approaches where the NPP vendor operates the plant for an extended period (i.e. several years or the entire NPP life) following commissioning.
— Engineering, procurement and construction (EPC) contracts, with the owner providing overall coordination.
— Engineering and procurement contracts, with construction and commissioning performed by the owner (with technical assistance from contractors).

Whatever the contract model, the owner/operator holds the final responsibility for all nuclear safety aspects of a nuclear installation. The owner/operator is responsible for production and sets the cost of electric power to the electric power distribution company. Therefore, it is essential for the owner/operator to check construction and installation of SSCs before they are turned over at the end of commissioning to make sure they adhere to requirements defined in nuclear legislation, regulations, applicable codes and standards, contract specifications, and in any other pertinent document.

Ideally, the owner/operator would have resources to confirm that all requirements contained in these documents have been met. In reality it is not practical for the owner to check for compliance by inspecting and testing every single SSC in the plant. Therefore, to expedite the execution of a commissioning programme, some confirmation activities are usually entrusted to suppliers/constructors or outsourced to qualified organizations.

There are many possible combinations of construction management and commissioning implementation plans. Table 2 describes five typical examples of project implementation approaches and how they impact commissioning.

As shown in Table 2, the division of responsibilities for commissioning varies depending on the construction contract approach adopted and the owner/operator's strategy. Commissioning is the last quality management activity administered by the owner/operator. While planning commissioning, the owner/operator will do an analysis and balance the resources to be deployed against the benefits likely to be accrued.

There are several possible models concerning the owner/operator's involvement in commissioning. The most common approaches are listed below:

— Owner/operator checks, inspects and tests SSCs in the field, as construction proceeds.
— An entrusted architecture–engineering firm checks, inspects and tests SSCs in the field and compiles confirmation records. The owner/operator reviews the records.
— Owner/operator or an entrusted architecture–engineering firm checks the records which vendors have prepared for commissioning. The owner/operator or an entrusted architecture–engineering does a walk down check in the field before turnover, but does not participate in the commissioning tests.
— Owner/operator receives the commissioning records of tests and inspections, conducts random checks on a graded basis and archives the records without a complete review of all items in the records.
— Owner/operator performs an owner's review mainly focused on safety, quality and performance.

The owner/operator will develop a test confirmation strategy for the commissioning turnover. There are several factors to be considered when developing the strategy from the viewpoint of nuclear safety and operations reliability. Some of these to be considered for an overall plan are:

— The owner's human and financial resources available for commissioning;
— Regulations regarding SSCs significant to nuclear safety;
— Experience and qualifications of the equipment suppliers regarding installation and preoperational testing;
— Experience and qualifications of the construction/installation contractors;
— Construction methodologies such as field designs, pre-fabrication, packaged SSCs and large modular construction;
— Degree of quality assurance and quality control for each SSC during fabrication and installation;
— Differences in practices between the owner/operator and the vendors;
— Availability of qualified architecture–engineering firms acting on behalf of the licensee in implementing the commissioning plan.

TABLE 2. PROJECT IMPLEMENTATION APPROACHES AND THEIR IMPACT ON COMMISSIONING

Case	Responsibility for overall project	Division of responsibility for commissioning	
		Organization/group	Main responsibilities
Case A	Owner/operator	Construction	Verifications and prerequisites for preoperational tests
		Commissioning management	Preoperational tests (system functional tests)
		Operations (preparation)	Initial fuel loading and startup tests
Case B	Owner/operator	Construction	Verifications and prerequisites for preoperational tests
		Operations (preparation)	Commissioning management group I: preoperational tests (system functional tests)
			Commissioning management group II: initial fuel loading and startup tests
Case C	EPC contractor or main contractor	Construction	Verifications
		Commissioning management	Prerequisites for preoperational tests Preoperational tests (system functional tests)
		Operating organization (licensee)	Initial fuel loading and startup tests
Case D	EPC contractor or main contractor	Construction	Verifications and prerequisites for preoperational tests
		Commissioning management	Preoperational tests (system functional tests)
		Operating organization (licensee)	Initial fuel loading and startup tests
Case E	EPC contractor or main contractor	Construction	Verifications and prerequisites for preoperational tests
		Commissioning organization (main commissioning contractor)	Preoperational tests (system functional tests)
			Initial fuel loading and startup tests
		Operations	Operations carries out selected sets of commissioning tests, including preparations and confirmation of plant configurations, as per work requests from commissioning and in accordance with operating manuals and test procedures as approved by a commissioning management group

Note: In all cases, the organization responsible for construction (either owner/operator or EPC contractor/main contractor) takes ownership of commissioning. The various cases listed in the table reflect different owners' interests and cater to various local capabilities. The implementation model adopted should be the one best suited for the plant construction in the specific local environment.

Table 3 provides an example of how to develop a commissioning test strategy that considers system significance from the viewpoints of nuclear safety and operational reliability. In the table, ‘safety class’ refers to a classification of SSCs in an NPP (in this case into classes 1, 2, 3 and other) based on their nuclear safety significance (refer to IAEA Safety Standards Series No. SSG-30, Safety Classification of Structures, Systems and Components in Nuclear Power Plants [135] for further details on safety classification). Safety class is combined with an evaluation of potential impacts on reliable operation to determine overall significance. Once significance is defined, each item to be commissioned is evaluated (assigned a grade) from the viewpoint of its contribution to the entire system to determine the relevant commissioning items to target. Namely, a grading strategy concerning the commissioning items for each system should be developed. For example, systems related to reactor trip systems would receive more thorough commissioning attention (e.g. reviews, oversight) than those associated with a warehouse or administrative building.

TABLE 3. COMMISSIONING GRADING STRATEGY

Nuclear safety — reliable operation	Safety class 1	Safety class 2	Safety class 3	Other classes
Failure may lead to a loss of power generation in the long term	A	A	B	B
Failure may affect stable power production	A	B	B	B
Others	A	B	C	D

Note: A — Very significant; B — Significant; C — Somewhat significant; D — Insignificant.

Today, NPPs are constructed using a global supply chain. Practices may vary between countries; therefore, if practices are not explicitly described in contracts or other documentation, they may not be implemented. Ideally, careful attention is given to writing contract terms and defining agreements on the scope of delivery, developing the list and sequence of commissioning activities, and detailing the documentation and records to be provided. All requirements and expectations need to be spelled out and agreed upon by both the owner and the vendors or contractors.

5.3. COMMISSIONING COMMITTEE

It is helpful for all test phases, in particular the overall test phases, that coordination of the various parties involved be performed by a ‘multi-party working group’ usually called the commissioning committee. This committee is under the direction of the commissioning organization until fuel is loaded. Beyond this point, the operating organization is normally required to take over the coordinating role because it is the nuclear facility licence holder.

The commissioning committee is typically made up of representatives from each party involved, including organizations in charge of commissioning, operations, maintenance, construction, engineering and licensing. The overall plant commissioning manager and the operations shift supervisor should be represented.

Committee members are selected according to their skill and training as they relate to the commissioning test phase. Participants should have the authority to act on behalf of their respective organizations in their areas of responsibility. The regulator should be informed and may send their representatives to participate in the committee meetings.

Typical main tasks of the commissioning committee for each test phase are as follows:

- Checking that all prerequisites are met, including relevant system and field area conditions;
- Identifying risks and defining means and safety configurations that can be set up to prevent or mitigate possible incidents;

— Monitoring day-to-day schedules and coordinating test configurations, actual testing, and other activities carried out in the test area;
— Performing reviews and confirming satisfactory completion of testing;
— Verifying that all objectives, regulatory requirements and other conditions are met in order to proceed with subsequent tests.

Figure 17 shows typical commissioning committee interfaces and duties.

From the first fuel loading onwards, a plant nuclear safety committee (PNSC) typically replaces the commissioning committee. This committee oversees all commissioning and operating activities with the following focus:

— Approve reactor startup test procedures and any major changes to the procedures.
— Approve plans for initial reactor startup, including the testing that is to be conducted.
— Monitor progress of activities.
— Ensure that the test programme is conducted in accordance with approved test procedures, plant operating manuals, operating technical specifications and the safety analysis.
— Review and approve results of tests performed during the initial reactor startup.
— Analyse test results and plant status as presented by commissioning management, and approve initiation of subsequent commissioning phases.
— Request regulator release for starting the nuclear phase or the next power range test.
— Ensure test deficiencies and non-conformances are resolved.
— Recommend modifications to system design or operating procedures based on test results.
— Review and approve modifications of the system design, any changes to the equipment configuration, and updates to the operation manual.

Figure 18 shows typical PNSC interfaces and duties.

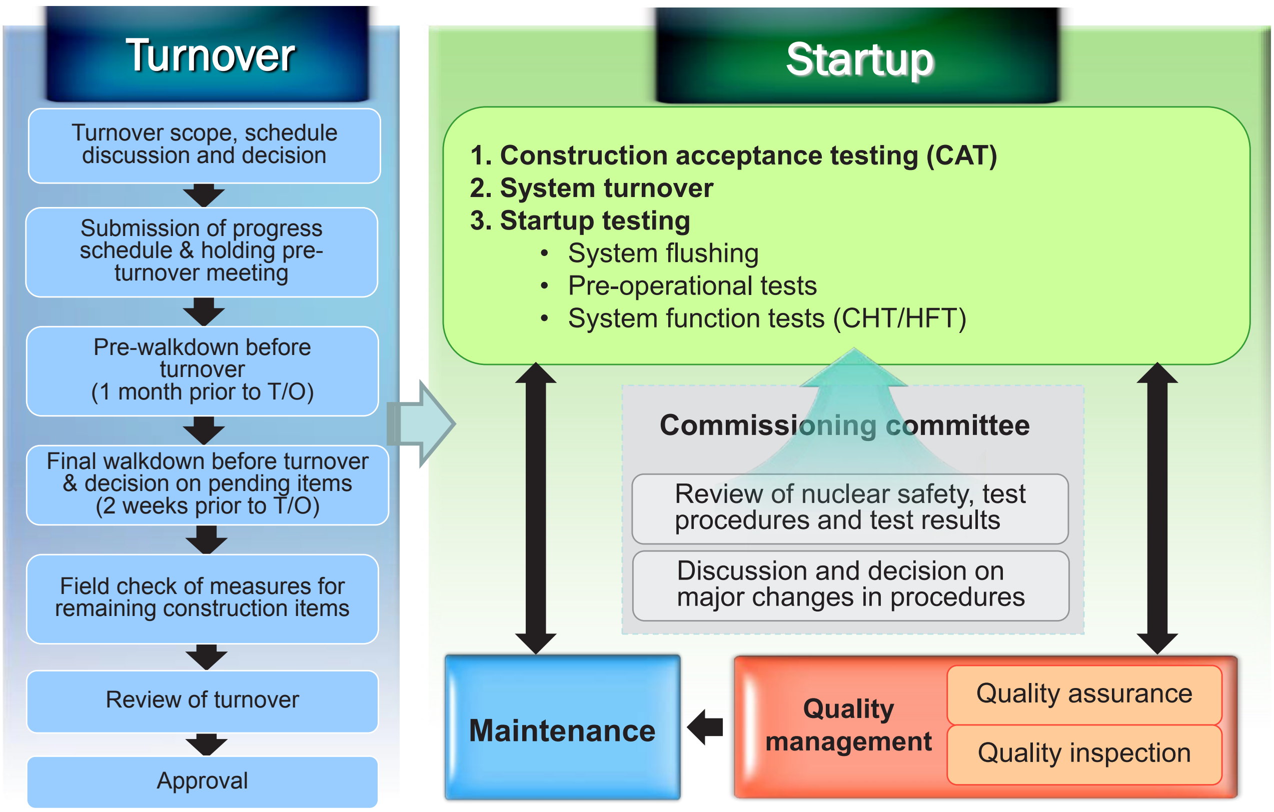

FIG. 17. System turnover process and commissioning committee interfaces and duties. HFT — hot functional test, T/O — turnover.

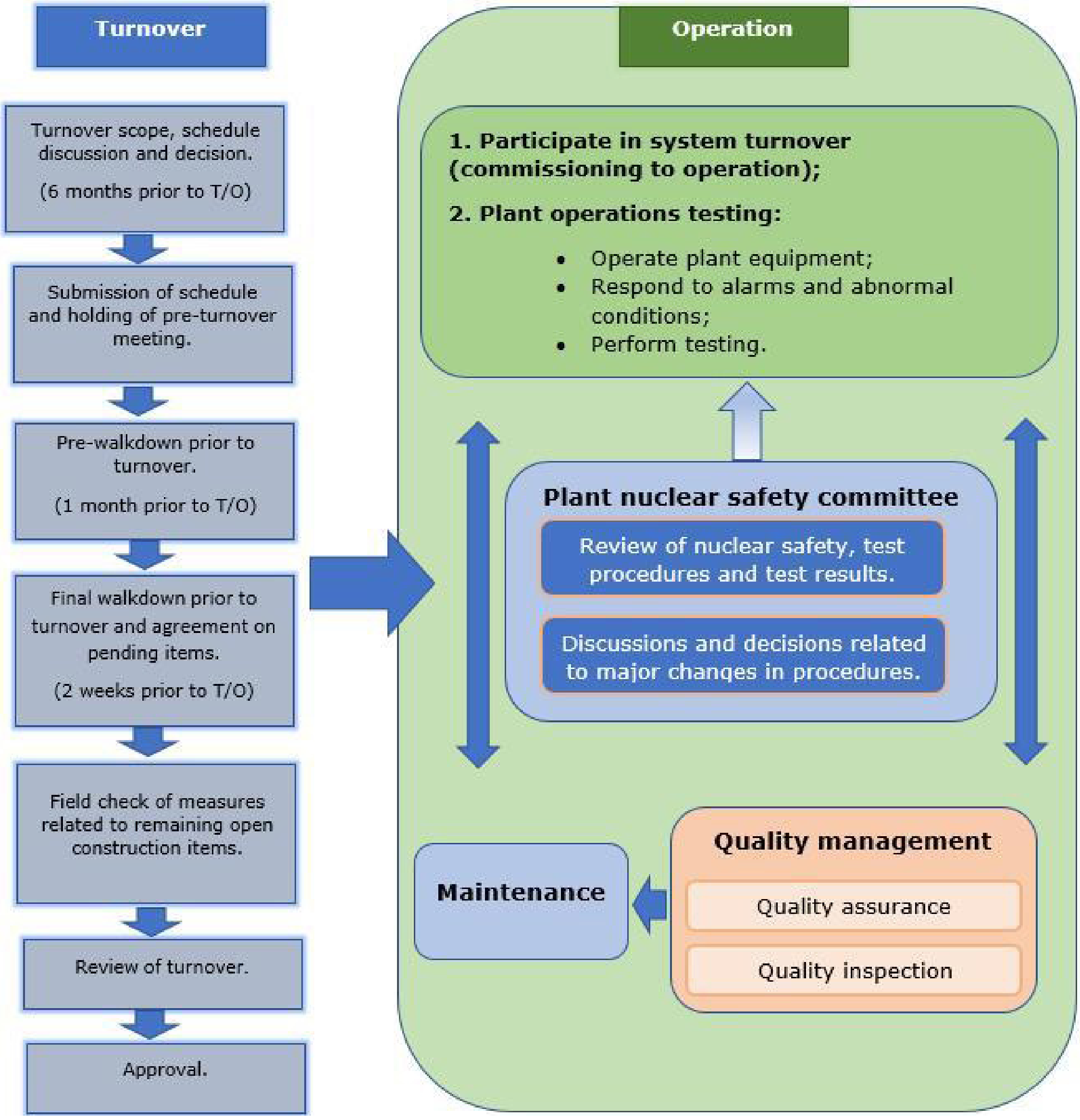

FIG. 18. Final turnover process and Plant Nuclear Safety Committee interfaces and duties.

5.4. STRUCTURE AND SIZING OF COMMISSIONING TEAMS

Commissioning is carried out by a commissioning implementation team, whose organization and structure are usually dependent upon the commissioning phase, the construction contract approach, national practices and local regulations. Different examples of commissioning organizational models were presented in Section 5.2. More detailed examples are included in Appendix I. Figure 19 contains a typical graph showing the variation of the commissioning staff depending on time and the commissioning phase.

5.4.1. Resource planning

Resource planning for commissioning is a key activity. IAEA Nuclear Energy Series No. NG-T-2.2 [136] discusses how to acquire and develop human resources needed to support commissioning, including staffing plans. It indicates that many NPP operating organizations initiate staffing plans for commissioning shortly after the decision is made to go forward with an NPP project, and finalize them 6 to 24 months prior to the start of component testing. In most cases, the operating organization has the lead responsibility for preparing this plan.

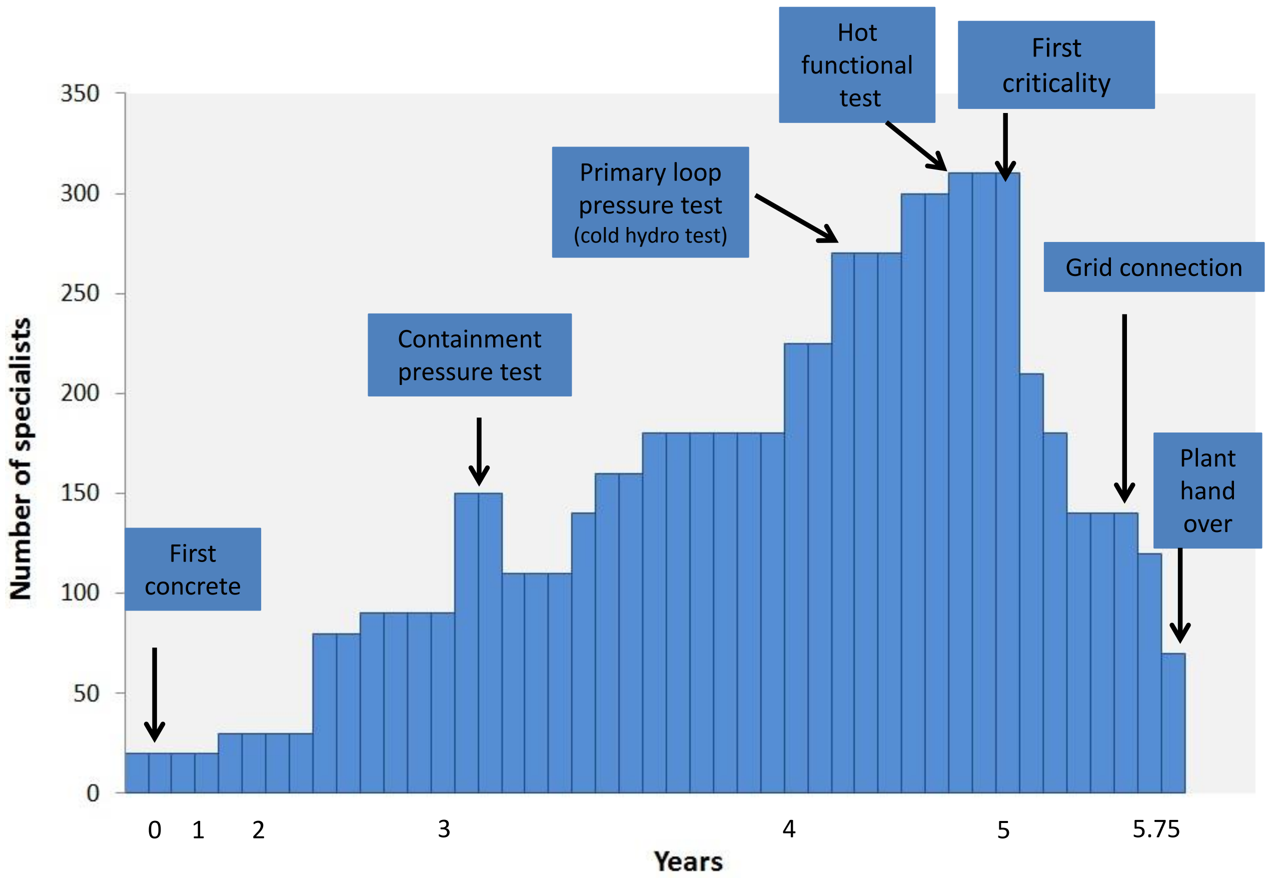

FIG. 19. Sample distribution of commissioning staff at the site versus time.

However, in some cases the main contractor or NPP project organization is responsible, or the plan is jointly prepared. This plan will include a schedule showing how the initial recruitment and selection of personnel will be implemented, as well as an analysis of the required number of people in each of the functional areas (job positions) that will be needed for commissioning, and the levels of experience/expertise needed for each position. Sufficient time needs to be allocated for project personnel to complete the training needed and to develop the competencies needed for their positions.

Many NPP operating organizations have found it useful to establish targets for the ratio of experienced to inexperienced personnel for commissioning in each position/function. These targets generally call for at least one third of the total number of personnel recruited for the NPP operating organization to have previous NPP operating experience. Other NPP operating organizations have established a target of having experienced persons in each of the 20 to 30 key positions for commissioning. For turnkey or split package NPP projects, some or all of the experienced personnel may be provided by the main supplier. However, in this case, the staffing plans need to include provisions for turnover of responsibilities for plant operations from the supplier to the owner/operator.

5.4.2. Commissioning implementation team composition

As commissioning proceeds, the make-up of the commissioning organization will gradually shift away from being construction related to become more operations based. Typical composition of the commissioning implementation team for various phases is described in Table 4.

TABLE 4. COMMISSIONING IMPLEMENTATION TEAM COMPOSITION BY PHASE

Commissioning phase/activity	Commissioning implementation team composition
Verifications and prerequisites for preoperational tests	Executed by construction staff with support from commissioning staff, or vice versa (executed by commissioning staff with support from construction staff)
Preoperational tests	Executed by commissioning staff with support from operations and construction staff, or vice versa (executed by operations staff with support from commissioning and construction staff)
Initial fuel loading and startup	Executed by operations staff with support from commissioning staff, or vice versa (executed by commissioning staff with support from operations staff)

In practice, the size and structure of the commissioning management groups and of the implementation teams may vary depending on the country and the local practices and conditions. The owner/operator will in any case be responsible for establishing the best plan for staffing the commissioning groups, considering its own resources and the resources made available by the NPP supplier and/or the technical support organizations.

5.5. TRAINING AND QUALIFICATION

SSR-2/2 (Rev. 1) requirement 7 states: "The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons" [8]. Personnel participating in plant commissioning thus need to be qualified at the level required for their activities. Hence, minimum qualification level requirements need to be defined for each commissioning activity and for all participating personnel. This extends to the operating organization, commissioning personnel, construction personnel, technical support organizations and supply chain participants. Some personnel may require regulatory authorization (e.g. shift supervisors, control room operators), and some specific commissioning activities may require special training (e.g. environmentally qualified splice training, IEEE recommended training for those involved in stationary battery installation and maintenance [110]). Training and emphasis on safety culture for staff or contractors who are new to nuclear projects is especially important, as practices tolerated in other industries or at other job sites may not be appropriate.

Typically, training of commissioning staff is conducted by their organizations in accordance with the commissioning schedule and national regulations and standards. It is designed and scheduled well in advance to ensure the availability of the required numbers of qualified personnel according to the scope and time limits of the commissioning activities (see Section 5.4.1), and later needs during the operating phase. Experience gained and lessons learned from current and past NPP projects and commissioning activities are incorporated into training material.

Reference [14] documents some specific training programmes relevant to commissioning, which include:

— Commissioning procedures;
— Reactor facility systems;
— Conduct of testing and maintaining the reactor facility in safe conditions;
— Procedural 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;
— Criteria for, and importance of, reporting incidents and deviations;
— Commissioning methods and techniques;
— Safety culture;
— Nuclear safety, industrial safety, fire protection, radiation protection and security;
— Design criteria, technology, and operational limits and conditions (or the equivalent) for the reactor facility;
— Environmental protection and waste management for spent fuel and radioactive waste;

— Full-scope simulator training of operators for reactor startup, regular operations, reactor shutdown and cooldown and handling of various transients, including accidents.

IAEA Nuclear Energy Series No. NG-T-2.2 [136] discusses how to acquire and develop the human resources needed to support NPP commissioning. Areas covered include staffing plans for commissioning, the development of commissioning training and its implementation, the content of the training and the methods used, the training material, the use of the control room simulator for training in support of commissioning and the organization of the training for commissioning. IAEA Nuclear Energy Series No. NG-G-2.1 [137] provides general guidance on management of human resources in the field of nuclear energy.

Training is recommended to address the administrative aspects of commissioning, such as:

— Regulations governing the conduct of testing;
— Rules related to procedural and design changes;
— Procedures regulating permanent and temporary modifications;
— Procedures regulating work control and equipment isolation;
— Interfacing and communication protocols between commissioning and other organizations, namely construction, design and operations;
— Procedures governing test limits and test boundaries for mechanical and electrical systems;
— Procedures governing incident reporting and processing of such reports.

Introductory courses on the NPP technology as well as training on system and equipment designs are also recommended. These will contain information surrounding licence requirements (e.g. technical specifications, safety analysis report requirements), emphasizing quality and safety aspects. It is useful to involve manufacturers and designers in this training, particularly for specific systems or equipment.

5.6. TEAM BUILDING

For new projects, personnel involved in construction turnovers and commissioning may not have worked together previously. Team building activities can improve the transition of systems between the organizations and develop a team better able to fully support commissioning activities.

Once key construction and commissioning personnel are named and in place, an off-site team building exercise supported by an outside facilitator can help develop the team. Such sessions seek buy-in to the commissioning plan, identify barriers to success and concentrate on resolving identified problems [138].

6. SAFETY ASPECTS AND LESSONS LEARNED

6.1. OPERATIONAL SAFETY AND COMMISSIONING

Section 4 of SSR-2/2 (Rev. 1) [8] describes how NPPs manage operational safety, and section 5 describes specific operational safety programmes for NPPs. Such methods and programmes go into effect when the plant begins the transition from construction site to operating NPP, which is typically considered to correspond to the time of initial fuel loading. Section 4.13 of the OSART Guidelines [133] is consistent with this approach, and details general safety expectations during commissioning.

During commissioning, a large number of construction, commissioning and operating activities take place concurrently. During test activities following core loading, the reactor may be in a unique operating configuration.[2]

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[2] For example, when initial containment radiological condition measurements are taken during criticality tests with an open reactor vessel to demonstrate stability of the reactor core.

Because these conditions may never be repeated in the life of the plant, and unique baseline configurations and behaviours may occur, the process of preparing and revising test procedures for these activities takes on particular significance.

As a result of testing equipment failures, unexpected equipment responses or human errors, the plant may go into an unplanned or unexpected condition. Planning for testing includes identification of such worst case situations or conditions. Good planning will define the important parameters to be monitored and the limiting values allowed to ensure that the plant remains in or can be placed in a safe state.

If abnormal conditions arise during testing, procedural compliance ensures that thorough step by step checks are completed in order to safely return the plant to a normal condition and continue the testing.

Plant radiological conditions can change rapidly during the approach to criticality or during power ascension tests. Communication between all plant personnel is essential at this time to avoid unexpected and potentially large exposures. Self-awareness, questioning attitude, peer check, error prevention tools and other human performance tools should be the subject of training and safety meetings conducted for all involved personnel.

Safety responsibilities for organizations and individuals involved in commissioning activities should be clearly documented and implemented according to the applicable national regulations and standards. Overall responsibility for nuclear safety rests within the operating organization, the licensee.

SSR-2/2 (Rev. 1) provides information on aspects of operational safety including safety policy and culture, operational limits and conditions, qualification and training of personnel, performing safety related activities, monitoring and reviewing safety performance, controlling plant configuration, management of modifications, equipment qualification, ageing management, records and reports, security, emergency preparedness and accident management, radiation protection and management of radioactive waste, fire safety, non-radiation-related (industrial) safety and operating experience feedback.

6.2. COMMISSIONING LESSONS LEARNED

6.2.1. IAEA sources

In 2004 the IAEA published IAEA-TECDOC-1390 on construction and commissioning experience with evolutionary water cooled NPPs [95]. In that publication, some specific projects were reviewed (Qinshan, Kashiwazaki-Kariwa, Lingao, Yonggwang and Tarapur), and safety and licensing regulatory and quality assurance issues were discussed. To shorten commissioning periods, the publication emphasized the importance of:

— Establishing experienced, single-project teams early to control finance, schedule and quality.
— Using good electronic document handling processes.
— Ensuring training and oversight of local participants in scheduling techniques, quality control and procedures.
— Working by functional block (e.g. pump house) for contracts and turnovers rather than by discipline.
— Establishing commissioning control points to check and confirm that commissioning has proceeded correctly and results have been duly documented.
— Using dedicated system engineers responsible for all aspects of commissioning a plant system or a group of systems.
— Using a formal commissioning clarification request process to address design related issues. The requests are responded to by engineering and closed out by the system engineers.
— Minimizing design changes during construction and commissioning, and integrating construction and commissioning feedback into issued designs.

IAEA Nuclear Energy Series No. NP-T-2.7 [94] on project management in NPP construction contains information regarding the commissioning phase of NPP projects (section 4), and its annexes provide descriptions of a number of NPP projects, including some lessons learned. Lessons identified related to commissioning include:

— Prepare a commissioning schedule based on a reference plant project and seek ways to improve on it.
— Hold daily communications meetings to coordinate efforts with construction and commissioning.
— Ensure mandatory participation of operations and engineering staff in commissioning.

- — Have well-defined milestones for system transfer to commissioning and then to operations.
- — Develop detailed commissioning schedules early.
- — Use electronic tools to aid commissioning staff in managing work permits, work packages, nuclear material and physics calculations.
- — Turn over plant systems as early as possible and gradually build up operations staffing and capability.
- — Use a component safety grading system to decide which items are formally reviewed and accepted by owner staff in the turnover processes, and those for which such acceptance might be delegated to suppliers.
- — Define roles and responsibilities for test planning, scheduling and control (construction, commissioning, operations, etc.).
- — Turn over plant systems to operations immediately following commissioning.
- — Use a ‘build clean’ concept during construction and increase pre-commissioning verifications to reduce flushing requirements and duration of commissioning testing.

IAEA Nuclear Energy Series NP-T-1.3 [125] provides operating experience and lessons learned related to power uprates, including some specific issues related to use of ultrasonic flowmeters and their commissioning.

The IAEA’s Nuclear Safety and Security Department maintains a comprehensive list of good practices observed during OSART Missions available at www-ns.iaea.org/reviews/good-practices.asp. Those relating to commissioning include having good control of commissioning hold points (Tianwan, China, 2004); having plans for the participation of operating staff in commissioning (Lingao, China, 2001); having experienced on-site design teams (Tianwan, China, 2004); having computer codes for analysing the operability of fuel rods under stationary, transition and accident conditions (Tianwan, China, 2004); and having efficient software for turnover management (Lingao, China, 2001).

6.2.2. Lessons from Chernobyl

The Chernobyl accident in 1986 pointed to the need for a strong nuclear safety culture and regulatory regime and clear understanding of the reactor design when tests are being conducted on an NPP. The accident occurred during testing of the capacity of turbogenerator No. 8 to supply power during its rundown for the unit’s internal requirements [139].

Safety Series No. 75-INSAG-7 [139] states:

> “The main idea of the programme is to test the design basis conditions as realistically as possible and there is nothing wrong with the programme itself. In the light of contemporary approaches to the development of testing programmes for conducting similar tests at nuclear power plants, the programme documentation in question is not entirely satisfactory, primarily in terms of its safety measures. However, the operating documentation as a whole (regulations and instructions), together with the programme in question, provided sufficient basis for the safe testing of the planned operating conditions. The causes of the accident lie not in the programme as such, but in the ignorance on the part of the programme developers of the characteristics of the behaviour of the RBMK-1000 reactor under the planned operating conditions.”

Other INSAG reports [140, 141] speak to the importance of safety culture with respect to this event, including the establishment of safety limits and understanding the consequences in terms of safety of violating them. The establishment of a robust nuclear safety culture is thus seen as a prerequisite for commissioning activities.

6.2.3. Joint Research Centre Institute for Energy

The European Clearinghouse within the Joint Research Centre Institute for Energy has prepared summary and topical reports on operating experience feedback related to events occurring during construction and commissioning of NPPs [142, 143]. The reports refer to 247 IAEA Incident Reporting System reports, 2 Working Group on the Regulation of New Reactors reports and 309 licensee event reports on civil structures, electrical components and mechanical components. The JRC reports summarized selected lessons learned on specific SSCs. A trend analysis conducted on these events emphasized the need to minimize the number of deficiencies during construction, manufacturing and commissioning of a new reactor, as they can be major failures that remain latent for a long time and have safety consequences during operation. Some specific recommendations are summarized in the sections that follow.

6.2.3.1. Commissioning test timing

Functionality of any component normally on standby should be regularly tested, as a long period of inactivity could alter its integrity and some aspects of its functionality or operability.

6.2.3.2. Scope of commissioning tests

(a) Test conditions

Safety systems should be tested under simulated real accident conditions, and if that is not possible, specific arrangements should be made to conduct alternative acceptance tests, quality assurance investigations, etc.

(b) Comprehensiveness of tests

Test scope should include all components and devices used during normal operation and those which could be used under accident conditions, including passive components such as strainers and pipes (as they may be clogged), and manufactured components, even if they are delivered with proper documentation, as quality control during manufacturing may still have been deficient.

Automatic startup of systems after a power disruption should be tested.

(c) Fragmented tests

As far as possible, safety systems should be submitted to overall functional tests to ensure not only the performance of each single component, but that of the whole system, to take into account component interactions.

(d) Non-actuation tests

Tests should be designed to detect unexpected (spurious) actuation of a safety system.

(e) Commissioning of different units

Commissioning tests should be repeated with the same scope for all units in multi-unit nuclear generating stations, because each unit will be unique, if not from the point of view of design, then most likely from the point of view of installation.

(f) Simultaneous tests

Commissioning test procedures should take account of the fact that tests conducted simultaneously may have an influence on each other’s results.

6.2.3.3. Documentation of commissioning tests

Acceptance or commissioning tests should not refer to installation drawings, which may be inaccurate. Instead, they should refer to the original design drawings.

6.2.3.4. Commissioning test acceptance criteria

Test acceptance criteria should allow testers to verify not only the functionality of systems or components but also their performance.

6.2.3.5. *System reconfiguration after commissioning tests*

The reconfiguration of systems after commissioning should be checked for non-conformances.

6.2.4. United Kingdom Royal Academy of Engineering

The United Kingdom Royal Academy of Engineering issued a report on behalf of Engineering the Future on nuclear lessons learned for new build projects [144]. In its conclusions, the authors emphasized the importance of proper transfers from construction to commissioning and operations, and how to facilitate such transfers. It also recommended the implementation of a rigorous quality assurance programme to ensure when a handover occurs between one contractor and another that the job is complete, correct in all respects and ready for handover. This will help ensure that errors do not accumulate, and that when commissioning takes place its focus is not diverted to discovering and rectifying construction and installation errors.

To facilitate the transfer of responsibility and knowledge from construction teams to commissioning teams, and then on to the station operations staff, the report recommended that commissioning and station operations teams be appointed early and be actively encouraged to collaborate. It did caution however that contractually the "integration of operating staff early in the process may present challenges given the timescale of construction, and there will be a need for approved simulation facilities and trainers consistent with plant that may have contrasting operational characteristics to the current fleet."

6.2.5. Electric Power Research Institute startup programme guidelines

EPRI has captured lessons learned from 30 experienced startup professionals in a report [145] so that these lessons can be evaluated and implemented where appropriate to improve new plant startup programmes. The individuals had a combined 210 years of startup experience in domestic and international plants. Sixty six specific recommendations are provided in the report which can be used to implement improvements in the overall programme rigour, schedule, equipment and personnel performance.

Almost half of the recommendations (31 of 66) are in the area of testing procedures, strategies, techniques and technologies. Typical recommendations within this area deal with procedure quality, digital system testing, testing with plant instrumentation, dealing with unexpected events during system testing and improving foreign material exclusion controls. The recommendations on digital systems are significant, as new NPPs and modifications to older NPPs have increasing amounts of digital equipment that can behave differently than former analogue components.

6.2.6. Construction Industry Institute (CII) research

CII has done extensive research over the years on construction best practices, including planning for startup. A research initiative in this area [138, 146] found that:

> "Project management and the perception of project success must be aligned with a new paradigm: *mechanical completion is not the project objective; successful commercial operations is*. Successful commercial operation requires a successful startup. The message is evident—*if you want a successful project, you must plan for a successful startup*.
>
> "Further analysis of startups indicates that there is a reasonably strong correlation between startup success and extent of startup planning. The message is again clear: *effective startup planning requires that the right issues be addressed by the right people at the right time*" [138].

Reference [138] contains 26 tools to help plan successful startups. These tools are applicable to NPP commissioning activities, however they are used starting at the very onset of project planning. Some early tools facilitate ensuring senior management commitment to startup planning, getting realistic forecasts of startup durations and costs, developing an execution plan, obtaining operations and maintenance input, and assessing risks and incentives. The research also includes an assessment method for evaluating startup readiness based on usage of the 26 tools.

6.2.7. Building Commissioning Association survey

In the spring of 2014, the Building Commissioning Association (BCA) in cooperation with several North American organizations, surveyed owners and project decision making managers of large property portfolios of higher education, hospital and government facilities. The purpose of this anonymous survey was to discover how commissioning is carried out in multi-facility, sometimes multi-site portfolios, and the challenges that owners and managers experience in doing so. The survey is documented in Ref. [147].

The results documented are necessarily more directly applicable to non-nuclear projects, however several applicable themes were evident. There appeared to be a shortage of management support and funding for comprehensive commissioning in portfolio projects, especially for existing building system retrofits. The report recommends that owners and commissioning service providers:

— Solicit/select work based on relevant and specific qualifications;
— Engage commissioning service providers in time to work with the design team;
— Make time to create the owner's project requirements together;
— Define clear expectations for all participants in the project;
— Ensure project managers support commissioning milestones while managing construction;
— Document integrated project team commitments;
— Train operations staff well;
— Verify operation through ongoing or periodic monitoring and occupant inquiries.

6.2.8. Lessons related to incomplete or inadequate testing

Supplier financial and time constraints can contribute to complex technologies being introduced into the nuclear industry prematurely, with only partially verified designs. Models may not have been updated and confirmed to accurately account for new or extrapolated designs. Some jurisdictions have updated their modification procedures to require engineers to consider earlier compensatory testing, such as proof of concept testing, FATs, SATs or pre-installation mock-up tests. If such testing cannot validate critical design requirements and assumptions, then compensatory measures such as enhanced modeling or oversight for verification of critical attributes (as described in Section 4.6) should be specified during the design phase.

6.2.9. Design features to facilitate commissioning

Ease of commissioning is a concern that should be addressed during the design process. Commissioning specialists should be part of formal design reviews to help ensure that necessary design and commissioning requirements can in fact be tested or otherwise proven in the field.

Some system designs have incorporated specific features to aid in the commissioning process. For example, Japan reported that the addition of technical consoles in the MCR and a test data acquisition system facilitated commissioning of the Tomari Unit 3 NPP [3].

The operator's main console for the integrated digital I&C system was small and could be simultaneously accessed only by two operators. However, many test operations need to be carried out in parallel during system functional testing and during later annual refuelling outages. Tomari Unit 3 added seven technical consoles to the design through which technicians could operate components or systems with permission of the operations crew. These consoles could help improve the efficiency of pipe flushing, trial operation of components, adjustment and tuning of I&C systems, and system functional testing during construction.

A test data acquisition computer system (brand name: MIDLE) was prepared for collecting and recording test data. The station's process computer system was designed to allow for connections to the data acquisition system. MIDLE was connected to the process computer system during the preoperational tests and startup tests to collect plant parameters and data on the status of the electrical and I&C system. MIDLE could be detached from the system during normal operation.

New electrical and I&C equipment (e.g. metering hardware, 'smart' instruments, plant wide communications networks) can be specified during design. These can provide a greater selection of monitoring and diagnostic functions than was traditionally available with earlier NPP designs. They can make collection of commissioning and operational data much easier (minimizing the need to connect temporary instrumentation), facilitate analysis of these data, improve plant performance and ultimately reduce costs. Specially designed connections for commissioning test equipment such as load boxes or data acquisition equipment should also be considered.

7. SUMMARY AND CONCLUSIONS

Commissioning of large projects and systems such as NPPs is a complex and sophisticated technical specialty. It may be considered a specific and independent engineering discipline, as important as the more traditional ones such as electrical, I&C, mechanical or civil engineering. Experience in key positions and continuous learning are essential. While they are most needed during original plant startup, commissioning skills and processes are needed throughout a plant's operational life.

The transition from the construction phase to the commissioning phase of a project is important and needs to be carefully planned, scheduled and executed. Hazards present can change by the day or hour, and the facility can be in a constant state of change. Clear ownership over specific plant systems and components, and an orderly process for turnover between work groups are key. Enterprise commissioning completion management systems are an important tool in helping to achieve this.

Commissioning makes possible the safe and orderly handover of the applicable plant or systems from the constructor to the operating organization, ensuring system safety, performance and reliability. It also ensures that there is full availability and traceability of the information required to operate and maintain the plant. Commissioning tests systems to their fullest capability. Errors or omissions during the process can lie dormant for years, making themselves known only when a system must be operated during an emergency event. Great care and attention to detail are thus essential for all commissioning related activities, and these should receive the full attention of senior management of nuclear facilities.

Appendix I

EXAMPLES OF PAST ORGANIZATIONAL MODELS

There are several models for implementation of NPP commissioning. Variations depend on technology, local conditions and the type of experiences the team has. This appendix describes three approaches adopted in the past, which can be used or modified to suit local conditions in a newcomer or expanding country. Some models used on specific projects (Qinshan, Kashiwazaki-Kariwa and Tarapur) are also available in chapter 6 of IAEA-TECDOC-1390 [95].

I.1. FOUR DEPARTMENT MODEL

A first model assumes that the commissioning team is set up 24 months prior to fuel loading. Performance requirements are collected in a ‘commissioning specifications and objectives’ document, which includes requirements from all disciplines involved, namely: nuclear physics, safety and system engineering.

The commissioning organization is based on a four department model:

— Commissioning technical function, with a number of system engineers based on disciplines and system types (e.g. nuclear steam plant process, nuclear steam plant I&C, fuel handling, electrical, common services, thermal cycle). This group develops a commissioning programme aimed at demonstrating that all SSCs meet design requirements.
— Commissioning execution function, consisting of field crews which carry out testing. The crews may use resources from plant operating and maintenance departments.
— Production and support function, providing support to field commissioning crews. This group includes specialists in maintenance, chemistry, health physics and dosimetry (radiation protection), industrial safety, emergency preparedness, nuclear safety (reactor physics management) and thermohydraulics. They all provide support to the commissioning execution group.
— Planning function, which develops commissioning logic based on detailed commissioning procedures. This group schedules and monitors progress of planned field execution activities and emergent work, and issues daily and weekly plans.

All of the above functions need to be available before starting commissioning, and any necessary training of commissioning, operations and maintenance staff must be complete. Regulatory authorizations for operating staff must be in place before fuel loading. Control points for progress evaluation should be defined and incorporated into the schedule.

In this model, system engineers are appointed to be pivotal figures for systems, as they are responsible for preparing or supervising preparation of commissioning documentation. System engineers also interface with engineering and construction on design and turnover issues, assess commissioning test results and prepare test reports, issue commissioning completion certificates and commissioning history dockets, and prepare operating manuals, test procedures, system surveillance plans and preventive maintenance programmes.

The turnover process includes turnover package preparation and open item review. A turnover checklist includes:

— Compliance tables for safety functions and requirements;
— Seismic qualification requirements;
— Environmental qualification requirements;
— Grouping and separation performance requirements;
— Fire protection requirements;
— Containment extension requirements;
— Extreme weather (tornado, flood, etc.) protection requirements.

I.2. COMMISSIONING MANAGEMENT GROUP MODEL

A second model based on a commissioning management group structure is shown in Fig. 20.

The commissioning management group at the centre of Fig. 20 is a special temporary structure responsible for direct management of commissioning. It interfaces with or includes members of various disciplines as shown in Figs 20 and 21. The group prepares a commissioning coordinating plan that lists commissioning activities, the commissioning group responsible and due dates. The plan is developed at least two years before the start of commissioning.

To perform plant commissioning on this basis, a commissioning engineering management group is established that is led by a commissioning engineering manager as shown in Fig. 21. This group consists of Direction Commissioning Engineering Managers (DCEMs), who are responsible for all commissioning activities on a system or group of systems. A shift commissioning engineering management group provides operative control and coordination of commissioning tests on site. A documentation group is responsible for maintaining site commissioning and operating documentation, developing commissioning records and releasing the final test report. Finally, a scheduling group is responsible for development of commissioning schedules based on data provided by the DCEM group.

Management of equipment and system operation during commissioning is the responsibility of the plant shift supervisor (within operations). Technical management of commissioning is the responsibility of the Shift Commissioning Engineering Manager (SCEM). The SCEM coordinates activities with the plant shift supervisor. Commissioning requests are submitted by DCEMs and approved by the NPP chief engineer. The SCEM is responsible for coordination of commissioning activities during his or her shift. Operating personnel prepare the plant for commissioning tests according to approved commissioning requests, relevant test programmes and operating manuals.

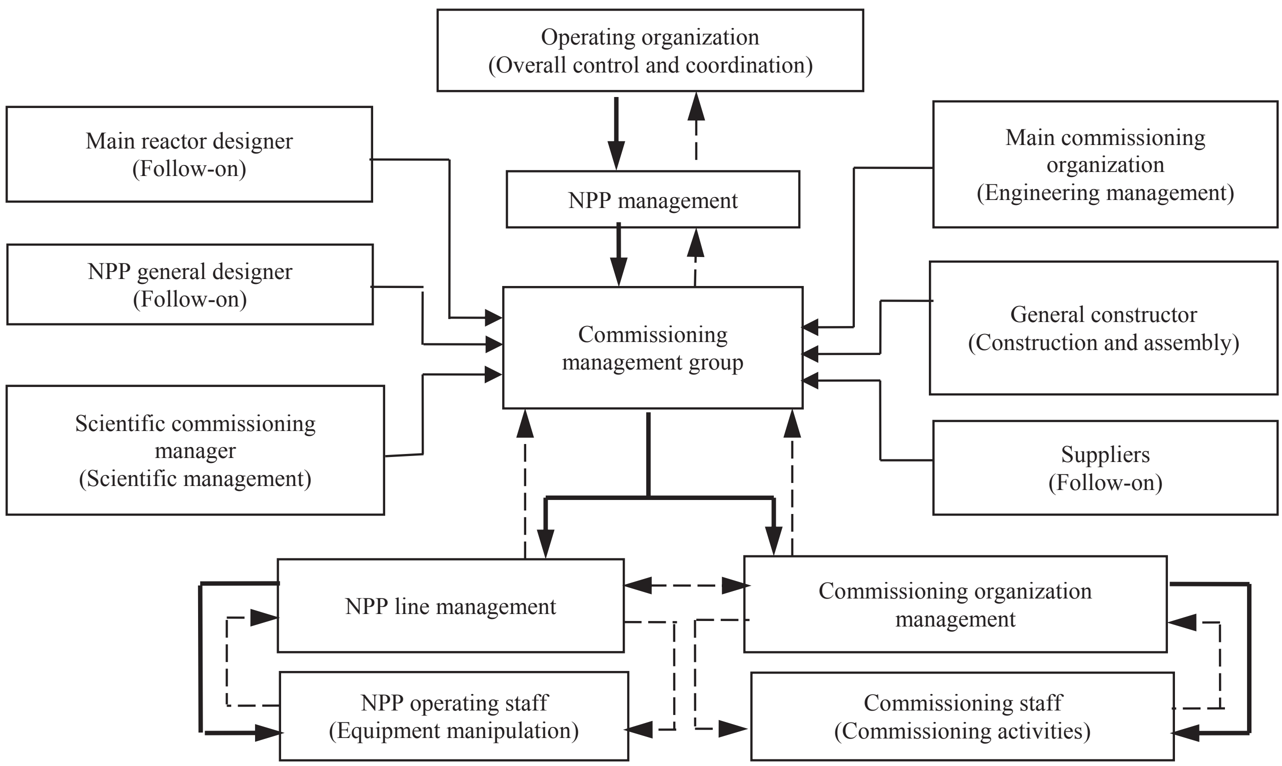


FIG. 20. Commissioning management group model.

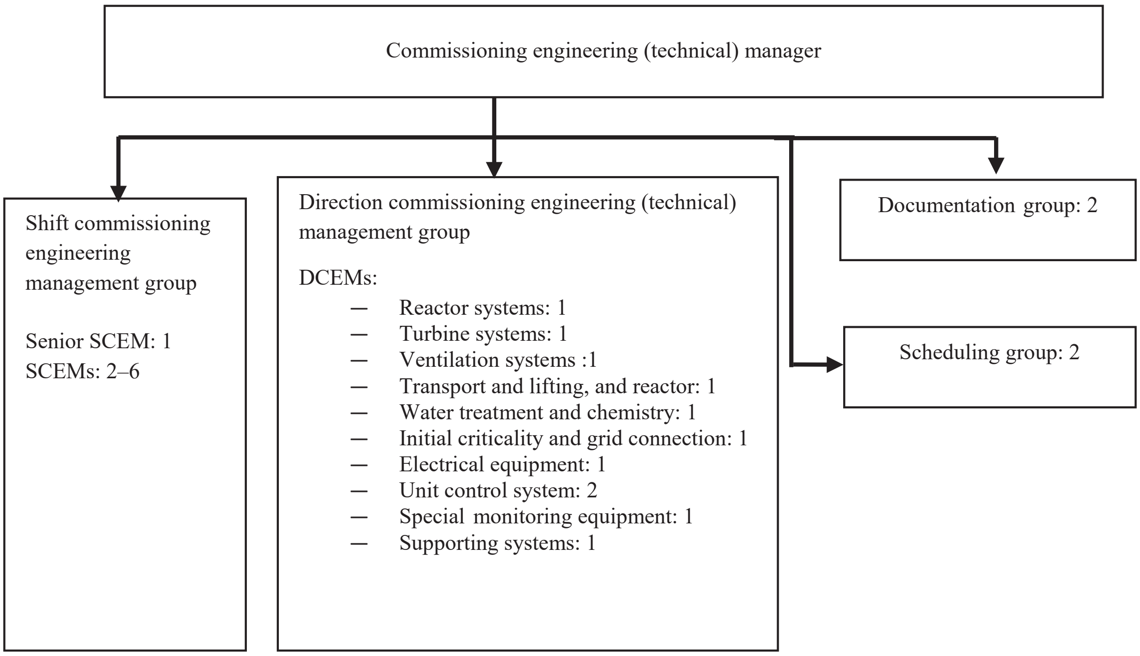


FIG. 21. Commissioning engineering management group organizational structure. SCEM — Shift Commissioning Engineering Manager, DCEM — Direction Commissioning Engineering Manager.

I.3. TWO STAGE MODEL

This model is adopted by most Japanese owner/operators, and involves the use of large module suppliers and large scope contracts. These cover design and procurement of all SSCs, assembly of large modules, commissioning and, in some cases, module installation at the site. Commissioning is executed by the main supplier and is a step necessary for turnover of systems and facilities to the owner/operator.

What is left for the owner/operator for commissioning is checking of overall safety and performance requirements, plant startup and commercial operation.

In this model, there are two kinds of commissioning tests: preoperational tests and startup tests (including initial core loading). Preoperational tests consist of component tests (e.g. flow-head characteristics of reactor coolant pumps, pressure test of containment vessel, flow rate tests of safety valves, inspection of seismic supports of pipes) and system or subsystem functional tests. These include for example the level control test of the chemical and volume control system volume control tank.

In startup tests, fuel is first loaded and subcritical tests of the reactor system are conducted. Then, initial criticality and reactor physics tests of the reactor system are conducted (at zero power), followed by system functional tests (e.g. steam generator level control test, control test of turbine bypass valves). Power and reactor physics tests of the reactor system (at several power levels) are conducted separately.

In the owner organization, since there are two stages of commissioning tests, two test working groups are established. These are a system commissioning test control group in charge of checking preoperational tests (system functional tests), and a startup test control group in charge of checking startup tests and system functional tests after initial core loading. The role of both groups is not to run the tests, but to oversee test execution via a test control team for each type of test. A typical structure for preoperational and startup testing for Tomari NPP Unit 3 is shown in Figs 22 and 23.

The startup test control group is established approximately 12 months before initial core loading. A team leader and about ten other members are assigned for each test from an operations preparation division, a nuclear core division or from construction. Plant operation is performed by operations shift personnel. If a large supplemental workforce is necessary for a startup test, the team leader can ask suppliers to supply the necessary workforce. System hot functional tests after initial core loading are carried out with the same structure as preoperational tests.

All tests, inspections and data collection for commissioning are done at the site, unless they can only be done at a supplier’s shop. The owner/operator usually witnesses any shop tests. Tests of heavy components and some pump characteristics fall into this category.

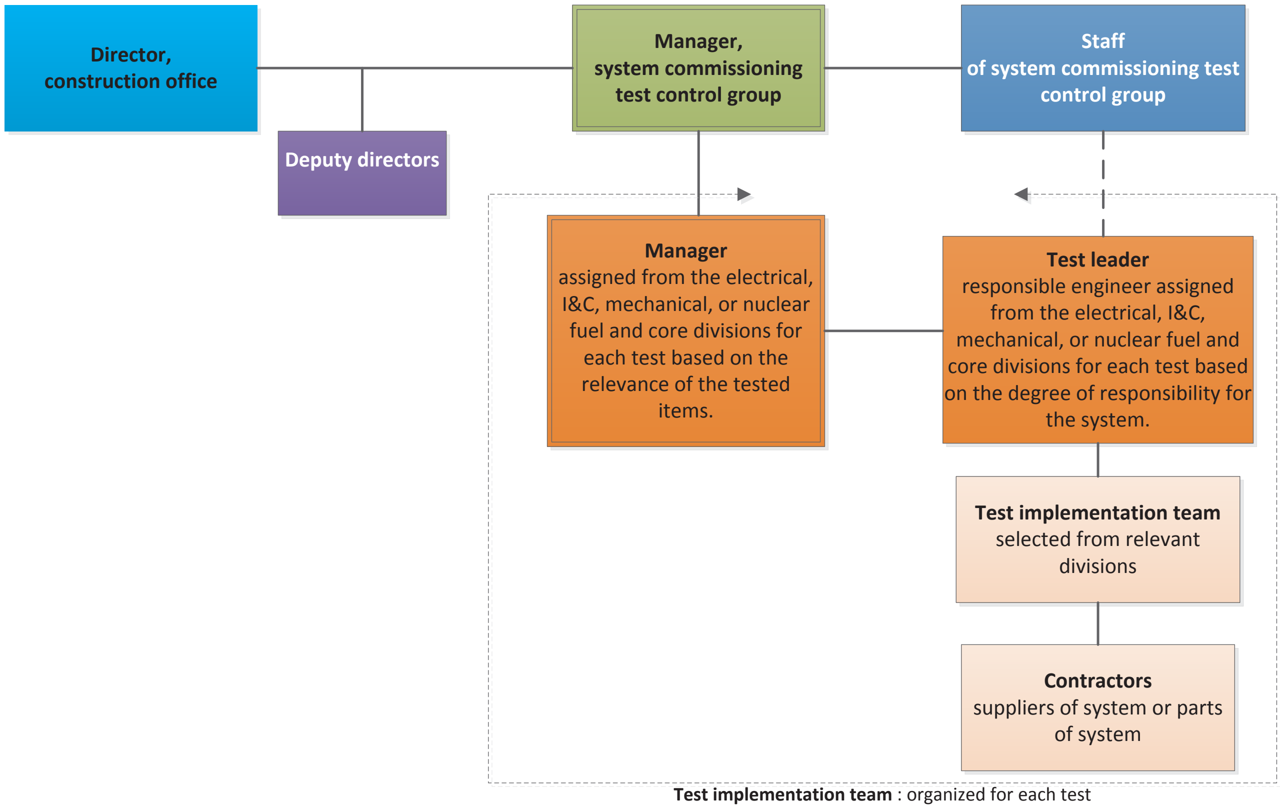


FIG. 22. Preoperational test control organizational structure.

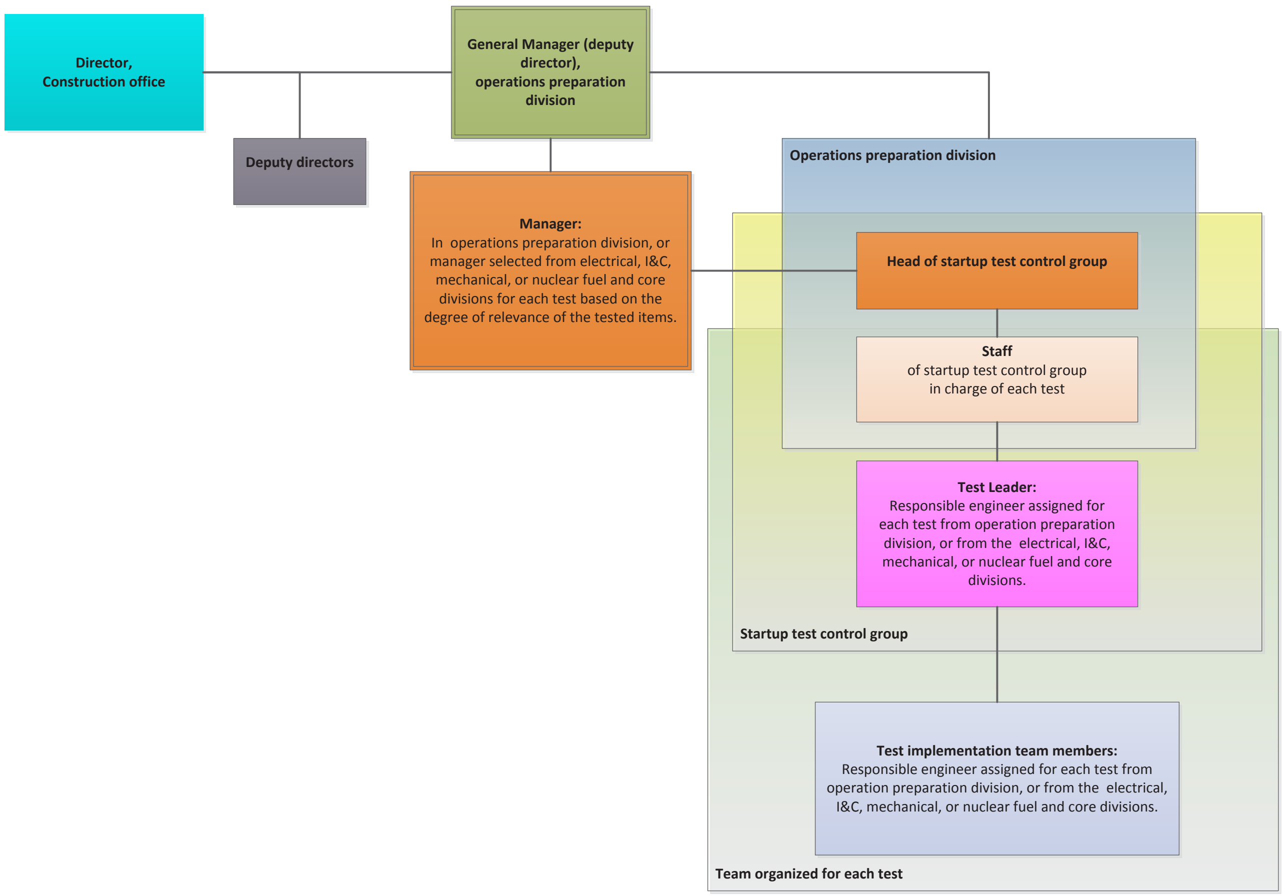


FIG. 23. Startup test control organizational structure.

Appendix II

TYPICAL EXAMPLE OF COMMISSIONING STAGES AND TEST SEQUENCES FOR NEW NPPs

This appendix is mainly based on practices and lessons learned on pressurized water reactors. Some PHWR information is added, however readers should refer to appendices A through D of REGDOC-2.3.1 [13] for more detail on typical commissioning tests for PHWRs.

II.1. OVERALL TEST SEQUENCE

Commissioning is generally performed in two main commissioning test stages: preoperational and operational. Preoperational tests (also called non-nuclear tests or preliminary tests) are performed before fuel loading, after turnover from construction to commissioning and verification of prerequisite fulfilment. They typically include:

- Individual system tests;
- Integrated functional system tests in cold conditions, including primary circuit cold hydrostatic test and secondary hydrostatic test;
- Integrated functional system tests in hot conditions.

Operational tests (also called nuclear tests), which start with fuel loading, typically include:

- Core loading tests;
- Pre-critical tests;
- First criticality and low power tests;
- Power ascension tests ending with full power tests and acceptance tests.

Figure 24 presents typical commissioning stages and a typical test sequence for a pressurized water reactor.

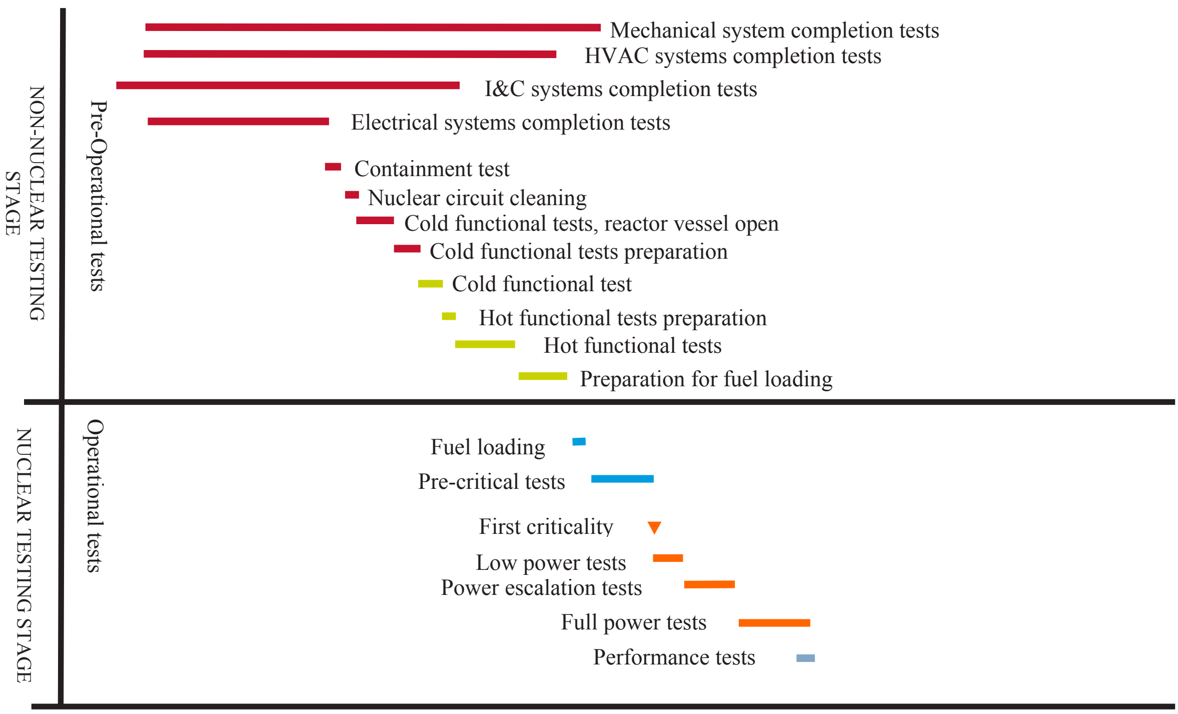


FIG. 24. Example of a stage oriented commissioning programme.

II.2. VERIFICATIONS AND PREREQUISITES FOR PREOPERATIONAL TESTS

Verifications and prerequisites for preoperational tests of components and subsystems cover items such as:

— 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;
— 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, load acceptance capability versus time and versus time and load (for generators);
— Pumps, fans or gas circulators: vibration, motor load versus time, seal or gland leakage, seal cooling, flow and pressure characteristics, lubrication, acceleration and coast down;
— Piping and vessels: pressure tests, leaktightness, cleaning and flushing, clearance from obstructions, support adjustments, proper gasketing, bolt torque, insulation, filling, draining and venting;
— I&C: voltage, frequency, current, circuit breaker operation, busbar transfers, trip settings, operation of interlocks, calibration.

II.3. PREOPERATIONAL TESTS

II.3.1. System preoperational tests

System preoperational tests can be categorized into:

— Tests identified in the safety analysis report to be performed on safety related and selected non-safety related SSCs to demonstrate their capability to perform in conformance with requirements imposed by the safety analysis. These tests demonstrate that system design features and the components operating as an integrated system perform as expected under normal and transient conditions.
— Tests performed on non-safety related components and systems, not required for safe shutdown and cool down of the reactor under normal and/or transient conditions. These systems are mainly support systems to process systems, such as fluid and electrical supply systems, ventilation systems and service systems. Preoperational tests on these systems aim to demonstrate operability and availability for tests of other systems.

System preoperational tests confirm that components and systems have required function and performance. They include the following:

— Reactor coolant system: system tests, component tests, vibration tests, pressure boundary integrity tests, etc.
— Containment system: pressure and leak rate test, personnel lock test and depression control system test.
— Reactivity control system: functional tests of chemical and volume control system, functional tests of rod cluster control assembly control system, etc.
— Reactor protection system: functional tests of reactor protection system, etc.
— I&C system: functional tests of I&C systems.
— Auxiliary and miscellaneous systems: tests on the emergency core cooling system (high pressure injection system and low pressure injection system), component cooling water system, essential service water system, heating and ventilation system, radioactive waste treatment system, fuel storage and handling system, radiation control system, etc.
— Moderator system (PHWR): tests of pumps, motors, cover gas recombination units, purification columns, poison addition system, leakage collection, addition and transfer systems, etc.
— Fuelling machines (PHWR): tests of fuelling machines, fuel transfer systems, spent fuel bay cooling and purification systems, and decontamination facilities.
— Power conversion system: functional tests on SSCs such as the main steam line, main feedwater control system, relief and safety valves, emergency feedwater system, turbine bypass valve control system, condenser

circulating water system, secondary make-up water system, chemical treatment systems, condenser water level control system, feedwater heater drainage systems, condenser vacuum and off-gas system, etc.

— Electrical systems: tests on the normal AC power distribution system, emergency AC power distribution system, DC system, etc. These include verification of the high voltage power supply and distribution system: prior to energizing electrical systems, certain tests are performed as required on power supply and distribution equipment, beginning with emergency AC and DC power supply and distribution systems. These tests should verify functionality of logic relays, protection devices, primary sensing devices and related interlocks. Circuit breakers, motor control centres, switchgears, bus bars and transformers are independently checked for insulation resistance, phase sequence, tan delta and polarization index, where applicable. For DC systems, tests of battery chargers, inverters, undervoltage devices and ground fault detection systems are required in addition to the AC tests mentioned above. Battery discharge tests at full load and for required duration are to be included. Emergency start and endurance tests for emergency generators are to be performed. Sequential load restoration tests within voltage and frequency limits are to be done by simulating failure of the normal power supply system. Emergency power supply systems should also be tested for capability to start under highest capacity design load. This may require the connection of temporary load boxes.

System preoperational tests should verify, among other things, that:

— Maximum design pressure of system is never exceeded;
— No cavitation is produced in valves or pumps;
— Pumps work at a suitable point on their characteristic curves;
— No water hammer or undesired pressure waves are produced;
— Vibration in components and pipes is acceptable;
— Displacements of pipes in cold conditions are acceptable;
— Valve actuators are correctly dimensioned;
— Manual valves can be properly operated;
— Motors are correctly sized;
— Interlocks comply with system design conditions;
— Protection settings are correct;
— Acceptable temperatures are not exceeded;
— Design currents and voltages are not exceeded;
— Fixed and elastic supports and their positions are correct;
— Redundancy of cable laying and sensing lines is adequate;
— Operating and emergency procedures are suitable;
— Safety systems operate properly under any plant condition;
— System performance, under cold conditions, is as specified.

II.3.2. Integrated system tests and overall tests

System preoperational tests are completed by system functional tests and phase tests, such as those detailed in the following sections.

II.3.2.1. Reactor coolant system and steam generator hydrostatic tests

After reactor closure and remaining preoperational tests of applicable systems are completed, hydrostatic tests are conducted. These demonstrate the integrity and leaktightness of the primary coolant system and steam generators which form the pressure boundary. Primary coolant system pressure is increased in a controlled manner to the level required to meet code and regulatory requirements. This phase of tests is usually called the cold functional test phase, or cold hydro test phase.

II.3.2.2. Reactor coolant system recirculation test

During cold and hot functional tests, if conditions warrant it, a useful practice is to perform a reactor coolant system recirculation test with dummy fuel in the core. This checks behaviour of the fuel assemblies and primary coolant circuit under both cold and hot operating conditions, and will detect design, manufacturing, construction or installation deficiencies before loading of nuclear fuel assemblies. For reactors with on-power refuelling features, the use of dummy fuel allows for fuelling machine testing under simulated operating conditions.

II.3.2.3. Containment structural integrity tests

After required system preoperational tests are completed, containment structural integrity tests are conducted to check leaktightness of systems and structures required to preserve the containment pressure boundary.

Primary containment pressure is increased in a controlled manner to a level required to meet code and regulatory requirements. This verifies the leaktightness of the primary containment, and also allows documentation of primary containment structure deformation modes, estimation of initial air leakage rates to confirm design requirements, and recording of baseline values for use in future periodic leak tests.

II.3.2.4. Hot functional tests

These tests involve operating reactor coolant and auxiliary systems together to check components and system interactions, and to verify performance of the whole plant under simulated normal operating conditions (i.e. normal temperatures, flows and pressures). Heat is derived from main coolant pump circulation, and not from nuclear fuel.

The tests verify the integrity of primary coolant and primary containment systems. They also allow data collection and equipment calibration under conditions as close as possible to normal operation. To carry out the tests, several systems are interconnected to simulate as close as possible the real normal operating state of the connected systems.

The primary coolant circuit is brought to design rated temperature and pressure utilizing reactor coolant pumps in recirculation mode without heat sinks in the circuit. Once rated conditions are reached, the following tests, assessments and verifications are carried out:

— Verification of readiness of safety feature actuation system.
— Verification of containment system integrity. This includes data collection on primary containment to verify that temperature limits of materials and components are not exceeded during normal operation and initial accident conditions.
— Verification of reactor coolant system integrity.
— Confirmation that the slopes of reactor vessel and steam generator level instrument lines are within allowable design tolerances. This ensures that instruments provide accurate indication.
— Garter spring location checks (PHWR).
— Liquid zone control function checks (PHWR).
— Containment ventilation performance checks. Depending on data collected, adjustments to ventilation system dampers may be necessary to balance air flows, confirm heavy water recovery system operation (PHWR only) and eliminate unwanted hot areas in containment.
— Verification of calculated thermal expansion and thermal movements of system components and of piping. Accuracy of piping stress evaluations is verified for example for guide support tolerances, in-line anchor movements and other design assumptions, and conditions at wall penetrations. Calibration of pipe restraints is also carried out, such as those for spring cans, snubbers and other types of flexible supports. Any unexpected interference created by thermal expansion should be addressed by engineering.
— Confirmation that system performance is as specified. This includes verifying that level control of steam generators works correctly; primary control loops for temperature, pressure and level control work correctly; reactor protection systems work according to design; control rod drives work according to design; all heat sinks work correctly; turbine speed control works according to design; and generator excitation, voltage regulation and synchronization equipment functions correctly.

II.4. INITIAL FUEL LOADING AND OPERATIONAL TESTS

Operational tests (also called ‘nuclear tests’ or ‘startup tests’) are performed after completion of hot functional tests. They typically include:

- — Tests in preparation for initial core loading;
- — Initial core loading tests;
- — Pre-critical post-core loading functional tests;
- — Initial criticality tests;
- — Low power physics tests;
- — Power ascension tests;
- — Plant performance tests.

II.4.1. Tests in preparation for initial core loading

After completion of hot functional tests, final checks and verifications will be conducted in preparation for core loading. The following preparatory tests are conducted as applicable to the reactor design:

- — Calibration and response checks of neutron flux measuring instruments and functional checks of alarm and protection circuitry. These are done making use of temporary neutron source assemblies.
- — Calibration of inverse count rate plotting system to obtain correct extrapolated inverse count rate ratio with correct core effective multiplication constant for required concentration of boron or other poison in the coolant.
- — Commissioning and preparation of continuous radiation monitoring system for service.
- — Tests for withdrawal and insertion speeds of reactivity control rods and checks of rod position indications, protective interlocks and circuits.
- — Testing of manual and automatic trip circuits and of shut-off rod insertion timing.
- — Water quality and boron concentration checks where applicable.
- — Vibration measurements.
- — Measurements of differential pressure across the core, with different combinations of pump operation.
- — Flow measurement during coast down of pumps.

II.4.2. Initial core loading tests

The initial fuel loading is normally subject to a specific authorization to be given by the regulator after assessment of plant and commissioning conditions. For PHWRs, the hold point is not only typically required for the first fuel loading, but also for removal of the shutdown guarantee/first criticality, after heavy water filling.

Initial core loading is carried out in a controlled manner. Depending on the reactor design, this may be done in different ways. The following tests illustrate the typical steps to be followed.

II.4.2.1. Neutron monitoring systems tests

Sufficient neutron poison is introduced into the core. This may be by injecting borated water or by control rod insertion. Neutron monitoring instruments are located within or adjacent to the core region during the core loading process, such that any changes in core reactivity can be observed.

Data or information from the neutron monitoring instruments is constantly observed so that unexpected changes may be detected and appropriate action taken. Following the loading of fuel, a visual inspection or other checks are made to verify that the loaded fuel configuration matches the design.

II.4.2.2. Radiation monitoring and radioactive waste system readiness tests

Before the start of initial core loading, radiological surveys and functional tests of radiation protection equipment and radioactive waste systems should be conducted. These tests should be completed following their turnover to operations and before initiating first core loading.

Radiation monitoring systems typically consist of on-site and off-site monitoring systems, occupational dose control systems (with individual dosimetry for personnel), systems for monitoring the radiation levels that equipment is subjected to, mobile radiation control equipment and sample monitoring equipment. A specialized control room may be present depending on NPP design.

The spent fuel pool's heat removal and water treatment systems should be operational. Systems for solid and liquid radioactive waste storage and treatment should also be commissioned and available. These can include technological facilities, control rooms and other personnel work areas, crossing corridors, changing rooms, showers, radiological control points and special laundry facilities. The detailed list of radiation protection and radioactive waste equipment and systems to be ready for use before initial core loading, and the detailed list of areas comprising the radiological control area should be provided in design or commissioning documentation.

II.4.3. Pre-critical post-core loading functional tests

Once fuel is loaded, hot functional tests are performed before initial criticality. The primary objective of hot functional testing is to verify adequacy of operating procedures and to ensure SSCs respond as expected.

With due allowances for functional differences during commissioning, plant operating procedures are used during reactor warm up from cold shutdown to zero power hot conditions. From this point onwards, hot commissioning tests can be conducted in sequence to the point of initial criticality.

In heavy water reactors, the first criticality is reached at approximately 60°C, which is why the pre-critical tests are performed before the reactor reaches that temperature. After first criticality, the low power tests in cold conditions (60°C) are performed, and then, the low power tests in hot conditions.

II.4.4. Initial criticality tests

Prior to actual criticality, calculations are made based on core design and current conditions to plan the approach to criticality. Formal approval should be received to start the approach.

This is followed by surrendering the guaranteed shutdown state, achieving first criticality, and conducting reactor physics tests aimed at checking reactor core characteristics and calibrating and/or verifying performance of reactivity and shutdown devices.

The following steps are common to the initial criticality tests for all NPP designs:

- Calibrations of neutron monitoring instruments covering the startup range are conducted.
- Final checks of equipment used to change reactivity are completed.
- Checks of safety related equipment required to change to the startup mode of operation are completed.
- The guaranteed shutdown state is surrendered.
- First criticality is achieved.
- Reactor physics tests are conducted aimed at checking reactor core characteristics (e.g. confirming reactivity worth of control devices and temperature impacts, neutron flux distribution).
- Reactivity and shutdown devices are calibrated and their performance is verified.

First criticality is normally achieved by slowly removing neutron poisons from the core in order to reduce negative reactivity in small steps, closely watching neutron monitoring while the core slowly moves towards criticality. As the reactor approaches a critical condition, the amount of positive reactivity added is reduced so that a long period of controlled reactor state is obtained. On PHWRs, a combination of poison removal and liquid zone control adjustments under control of the reactor regulating system is typically used to achieve this.

When criticality is achieved, a comparison of actual configuration to designed configuration is carried out to verify accuracy of design methods and calculations. If results of this comparison are outside allowable tolerances, the reactor should be returned to a subcritical state, until reasons for the discrepancy are understood and corrective action taken.

The initial approach to criticality is a procedure undertaken with a great deal of caution, because the reactor is in a potentially dangerous condition. Reactivity available is at its maximum (no fuel burnup has occurred), and the critical value of control variables is not precisely known. For example, if the approach to criticality is being made by removing poison, the critical poison concentration is only a design estimate (although it is generally quite accurate). Startups following poison outages or extended duration reactor outages provide differing starting core conditions that need to be carefully taken into account

A method used for approaching criticality is the power doubling technique. When starting with a subcritical reactor, the power doubling rule states that when an addition of reactivity causes a doubling in subcritical reactor power (count rate), then a further addition of the same amount of positive reactivity will make the reactor critical. What this means is that if you have previously added 1 mk to a subcritical reactor, and it caused subcritical reactor power to double, then the addition of another 1 mk will cause the reactor to go critical (note that at low power we measure reactor power change in decades, so a doubling of power represents approximately a 0.3 decade power change).

II.4.5. Low power physics tests

Once criticality is achieved, specific tests are conducted to verify core parameters and performance of reactivity control systems, and to ensure reactor physics parameters and shielding are behaving as expected. The reactivity coefficients of reactivity devices are measured to ensure they are in accordance with the safety analysis report.

Primary containment ventilation system performance is verified with the primary coolant at its rated temperature. The capability to maintain design parameters where required with the minimum prescribed number of active components in service should be tested. Verification of piping and component expansion is carried out, and thermal movement and vibration measurements for safety systems are recorded.

Operability checks of condenser steam dump valves and of atmospheric steam discharge valves and other heat removal system components are conducted. Testing of neutron monitoring instrumentation is carried out to verify that overlaps between startup range, intermediate range and high power range (as applicable) are adequate. This testing is to ensure that the core will be monitored from the subcritical state, through startup and low power conditions all the way up to and including 100% power.

Shutdown system equipment and trip set points should be adjusted for the expected power level at the test plateaus. Shut-off rods, control rods or other neutron absorbing equipment should be checked to ensure that it will be capable of controlling and shutting down the chain reaction at all times and under all expected conditions. Safety related emergency equipment should be tested to ensure it can perform its intended function.

II.4.6. Power ascension tests

II.4.6.1. Power ascension programme and tests

A series of commissioning tests should be performed during the reactor power ramp up at each power level specified in the commissioning programme. These tests are designed to confirm core characteristics; verify operation of control, safety and protective systems; and confirm the dynamic response of the nuclear steam supply system (NSSS) and the balance of plant, including the turbine generator. Finally, they confirm the NPP’s suitability to go into commercial operation. Potential tests include the following:

- — High power physics tests;
- — Tests of plant shutdown/cool down capability, including natural circulation if applicable;
- — Verification that power level transient capability is as specified in design and safety documentation;
- — Loss of off-site power tests and engineering safety features system availability tests;
- — Core protection calculator/core operating limits supervisory system verification at various power levels;
- — Tests of NSSS integrity monitoring system;
- — Biological shield survey test;

— Tests of reactor setback/stepback functions (PHWR);
— Digital control computer transfer and failure tests (PHWR);
— I&C system checks;
— Shutdown system equipment and trip set point adjustments at the test power levels.

II.4.6.2. Nuclear core physics tests

Core characteristics at low and normal temperatures should be measured at zero power in order to verify shutdown margins and reactivity worth under partial rod ejection conditions and complete control rod insertion. Physics test are held at each power ramp up step, for example at 25%, 50%, 90% and 100% power.

Core performance should be verified by undertaking a number of tests, for example:

— Verification of variable T_{avg} (average coolant temperature);
— Verification of steady state core performance;
— Fixed in-core detector check;
— Dropped/ejected control element assembly test;
— Xenon oscillation test;
— Core monitoring computer and software checks.

(a) Reactor operating margins

The following core monitoring computer systems checks should be undertaken on all reactor plant designs:

— Installed computer software and initial data constants should be verified.
— Computer displayed critical information should be compared to manually obtained data to verify that electrical connections are correctly configured and that internal computer data identification tables are correct.
— Computer system calculations of core thermal power should be compared to manual calculations to verify accuracy.
— Neutron monitoring instrumentation computer inputs should be compared to manually obtained data to verify accuracy.
— Results of core monitoring computer software calculations of operating parameters should be compared to design values. Engineering judgement should be used to verify accuracy of very complex calculations.

In some reactor designs, a core protection calculator function is available to continuously monitor local power distribution and margin of departure from the nucleate boiling regime. This prevents spurious reactor trips when safety margins are degraded through ageing. Also in some designs a core operating limits supervisory system is provided as an on-line monitoring function for local power distribution and departure from the nucleate boiling regime to assist operators in maintaining in-core parameters within the limits necessary to avoid spurious reactor trips and in maintaining operational margins within those allowed.

II.4.6.3. Power ramp up and transient tests

Dynamic response of the plant NSSS and balance of plant should be verified to confirm system stability under all thermodynamic transients throughout the operating power range. To this end, a number of tests should be performed to verify NSSS I&C logic during normal plant transients, fine tune control set points, and confirm the response of the NSSS and balance of plant. NSSS and balance of plant system piping vibration should be monitored throughout the system operating range, and the piping restraint design should be validated for such loads.

Tests typically performed during this phase include the following:

— Turbine load transients. Commissioning demonstrates the ability of the NSSS to automatically respond to turbine load changes (e.g. in 10% steps) and ramp load changes (e.g. of 5% per minute).
— Routine power load cycling. Although nuclear units typically operate as baseload at 100% power, a test should be run to prove that the plant can load follow if it is designed to do so and if contractually specified.

Such a test can, for example, consist of a 50% power reduction over a 2 hour period and a demonstration of xenon control capability over a period of 6 hours, followed by a 50% power ramp up over a period of 2 hours.
— Demonstration of load rejection capability. This test could be conducted to demonstrate capability to withstand turbine load rejections from any power level, with the reactor remaining on power and the turbine generator providing power to cover the required house load. At that point, reactor power should decrease to a level within the capability of the steam bypass system without the turbine overspeeding and without operator action. Such a test proves the reactor's capability to withstand a severe grid disturbance, remaining on-line and supplying its own house loads, while isolated from the grid, and being ready to restore its normal connection to the grid in a rapid sequence.
— Reactor power cutback. This transient is produced by a loss of one of the feed pumps. This test should demonstrate that the reactor power decreases and the reactor remains on-line with only one operating feed pump. The test should monitor that control rods drop as necessary, that reactor power is reduced and that control logic adjusts the turbine generator output to match the reduced reactor power. It should then be demonstrated that the plant can return to 100% power promptly (say within 2 hours) from the start of the transient.
— Turbine trip/natural circulation. This test demonstrates automatic reactor shutdown on turbine trip and establishment of natural circulation heat removal.
— Loss of off-site power. This test should demonstrate the ability of operators to achieve and maintain hot standby conditions using only emergency systems and emergency power, as would occur in design basis accidents. All systems should remain functional as designed.
— Remote hot shutdown capability (if required by local regulations). This test is designed to verify capability to remotely shut down the reactor, achieve and control hot standby conditions, perform a controlled cool down with depressurization, and remotely initiate and control decay heat removal.

II.4.7. Plant performance tests

Plant performance tests verify final plant performance and suitability for commercial operation. They may include testing of maximum electric output, thermal efficiency and reliable operation for a contractually agreed duration. For PHWRs, final testing of on-line refuelling capability is confirmed during this period.

Appendix III

COMMISSIONING RELATED RESPONSIBILITIES OF COMMISSIONING AND OPERATING ORGANIZATIONS

Activities	Organization	PREOPERATIONAL TEST STAGES			POSTOPERATIONAL TEST STAGES
		Individual system test before takeover for temporary operation	System operation and tests after takeover for temporary operation	Overall preoperational test stages before fuel loading (cold and hot functional testing)	After fuel loading
Commissioning					
Direction and coordination	Commissioning	Technical direction of commissioning, coordination and scheduling of tests and system transfers for temporary operation	Technical direction of commissioning and operation, coordination of system operation and tests/scheduling of tests	Technical direction of commissioning and operation, overall coordination and scheduling of test stages and transfer for nuclear operation	Technical direction of commissioning, overall coordination and scheduling of plant tests
	Operations	On-the-job training on system tests and operation, performing tests	Temporary system operation, performing tests, coordinating with safety authority	Temporary plant/system operation, performing tests, coordinating with safety authority	Technical direction of nuclear plant operation, supervision of test performance, relationship with safety authority, nuclear safety responsibility
Test preparation	Commissioning	System checks and acceptance from installation, test document issuance and updating, test preparation and prerequisite checks and validation	Test document issuance and updating, test preparation and prerequisite checks and validation, commissioning for particular systems according to test needs (if necessary)	Stage prerequisite checks and validation, test document issuance and updating, test preparation and prerequisite checks and validation, commissioning for particular systems and plant according to test needs	Stage prerequisite checks and validation, test document issuance and updating, test preparation and prerequisite checks and validation, commissioning for particular systems and plant according to test needs
	Operations	Review of test documentation, assistance with test preparation	Review of test documentation, prerequisite fulfilment checks, implementation of particular operating instructions	Review of test documentation, prerequisite fulfilment checks, implementation of particular operating instructions	Review of test documentation, prerequisite checks and validation, review and implementation of particular operating instructions
Test implementation	Commissioning	System test coordination and performance, commissioning for test performance	System test coordination and performance, commissioning for test needs and for system tests	Overall test coordination in MCR, commissioning for test needs and for system tests	Overall test coordination in MCR, commissioning for test needs and for system tests
	Operations	Operating manoeuvres in support of commissioning organization	System operation and operating manoeuvres	Overall system operation and operating manoeuvres	Overall system operation and operating manoeuvres
Test reports, punch list	Commissioning	Test result evaluation, test report issuance, system punch list/open item updating	Test result evaluation, test report issuance, system punch list/open item updating	Test result and test stage evaluation, test report issuance, centralized system punch list/open item management/updating	Test result and test stage evaluation, test report issuance, centralized system punch list/open item management/updating
	Operations	Test report review and validation, review and agreement on plant punch list/open item disposition	Test report review and validation, review and agreement on plant punch list/open item disposition	Test report review and validation, review and agreement on plant punch list/open item disposition	Test report review and validation, review and agreement on plant punch list/open item disposition

Activities	Organization	PREOPERATIONAL TEST STAGES			POSTOPERATIONAL TEST STAGES
		Individual system test before takeover for temporary operation	System operation and tests after takeover for temporary operation	Overall preoperational test stages before fuel loading (cold and hot functional testing)	After fuel loading
Operation					
Blocking/tagging — work and test permits	Commissioning	Direction of all activities, performance of all activities	Direction of all activities, supervision of activities, requests according to commissioning needs	Direction of all activities, supervision of activities, requests according to commissioning needs	Supervision of activities, requests according to commissioning needs
	Operations	Support of activity performance	Performance of all activities, requests according to operation and maintenance needs	Performance of all activities, requests according to operation and maintenance needs	Direction of all activities, requests according to operation and maintenance needs
System and plant operation	Commissioning	Validation of system operating procedures, system operation according to test needs	Validation of updates to system operating procedures, technical assistance for system operation, supervision of system operation/test need fulfilment	Validation of overall operating procedures, technical assistance for system/plant operation, supervision of system operation/test need fulfilment	Validation/updating of overall operating procedures as needed, technical assistance for system operation, supervision of system operation/test need fulfilment
	Operations	Validation of system operating procedures, operating manoeuvres in support of commissioning organization	System operating procedure updating as needed, operation and monitoring of systems according to operating procedures and test instructions/needs	Validation of overall operating procedures, operation and monitoring of systems/plant according to operating procedures and test instructions/needs	Validation of overall operating procedures, operation and monitoring of systems and plant according to operating procedures and test instructions/needs
Periodic tests	Commissioning	Validation of testing procedures during or in parallel to system tests	Validation of updates to testing procedures, technical assistance for test performance	Validation of updates to testing procedures, technical assistance for test performance	Validation of updates to testing procedures, technical assistance for test performance
	Operations	Review and validation of test documentation, assistance with test performance	Review and validation of updates to test documentation, performance of periodic tests, management of test result databank and documentation	Review and validation of updates to test documentation, performance of periodic tests, management of test result databank and documentation	Review and validation of updates to test documentation, management of periodic test scheduling and performance, management of test result databank and documentation
Maintenance					
Routine maintenance	Commissioning	Performance of routine maintenance	Supervision	Supervision	Supervision
	Operations	Assistance	Performance according to maintenance plan	Performance according to maintenance plan	Performance according to maintenance plan
Preventive maintenance	Commissioning	Performance of preventive maintenance	Supervision and technical assistance	Supervision and technical assistance	Supervision and technical assistance
	Operations	Assistance	Performance according to maintenance plan	Performance according to maintenance plan	Performance according to maintenance plan

Activities	Organization	PREOPERATIONAL TEST STAGES			POSTOPERATIONAL TEST STAGES
		Individual system test before takeover for temporary operation	System operation and tests after takeover for temporary operation	Overall preoperational test stages before fuel loading (cold and hot functional testing)	After fuel loading
Corrective maintenance	Commissioning	Performance of corrective maintenance	Performance of corrective maintenance	Performance of corrective maintenance	Performance of corrective maintenance
	Operations	Assistance	Assistance	Assistance	Assistance

Appendix IV

SAMPLE INSTALLATION COMPLETION/TURNOVER TO COMMISSIONING WALKDOWN CHECKLIST AND DECLARATION

IV.1. SAMPLE INSTALLATION COMPLETION/TURNOVER TO COMMISSIONING WALKDOWN CHECKLIST

SECTION A: GENERAL INFORMATION			
Installation completion declaration (ICD) walkdown date:		Unit:	
ICD No.:		ICD package title:	
Master modification No.:		Discipline modification Nos:	
System being turned over: or not applicable ☐		Location:	
Building being turned over: or not applicable ☐			
System or building No. being turned over:		Contractor(s):	
System or building was:	☐ Maintained in service with no modifications or major component replacements ☐ Kept in lay-up or shutdown state ☐ Modified/new		
Walkdown type:	☐ Partial walkdown ☐ Final walkdown		
		Name	Initials
Walkdown participant(s):	☐ Project engineer		
	☐ Construction		
	☐ Project management		
	☐ Operations		
	☐ Maintenance		
	☐ Design		
	☐ Others:		

Walkdown items to be addressed:

Item No.	**Description**	**Reference (post-walkdown)**	**ICD related (Y/N) (Y=must be addressed prior to turnover)**

IV.2. SAMPLE INSTALLATION COMPLETION/TURNOVER TO COMMISSIONING DECLARATION

SECTION A: GENERAL INFORMATION			
Unit:			
Installation completion declaration (ICD) No.:		ICD package title:	
Master modification No.:		Discipline modification Nos:	
System being turned over: or not applicable ☐		Location:	
Building being turned over: or not applicable ☐			
System or building No. being turned over:		Contractor(s):	
System or building was:	☐ Maintained in service with no modifications or major component replacements ☐ Kept in lay-up or shutdown state ☐ Modified/new		
Walkdown type:	☐ Partial walkdown ☐ Final walkdown		
		Name	Initials
List of walkdown participant(s):	☐ Project engineer ☐ Contractor ☐ Project management ☐ Operations ☐ Maintenance ☐ Design ☐ Others:		
		Name: Organization:	
Date of ICD walkdown:		Additional comments attached: ☐ Yes ☐ No	
Prepared by: _____________________________________ Date: ______________			
Scope of this ICD: As shown on attached marked up operational flowsheet: ☐ Yes ☐ No			

Design review:

- As-built/field changes reviewed, documented and acceptable to proceed to commissioning.
- No outstanding design issues except as identified in 'open item list'.

Responsible individual, design: ____________________________________ Date: ______________

Commissioning review:

- Construction work activities in enterprise system reviewed and confirmed closed out, or incomplete items are listed as open items.
- System or building walkdown completed and open items documented.
- Planning and scheduling department notified of imminent construction completion.
- Material condition and housekeeping of turned over system or building is acceptable.
- Notification to operating organization regarding construction completion prepared and ready for issuance.

Responsible individual, commissioning: ______________________________ Date: ______________

Construction declaration:

- Applicable non-conformances or adverse condition reports closed or listed as open items.
- All field changes/as-builts have been documented, resolved or listed as open items.
- System, building or portion bounded by this declaration is complete, or incomplete items are listed as open items.
- Construction work activities in enterprise system have been reviewed and confirmed closed out, or incomplete items are listed as open items.
- Any non-modification actions related to this declaration are complete, or incomplete items are listed as open items.

Responsible individual, construction: ________________________________ Date: ______________

Remaining open item list

Item No.	Description	Responsible individual	Date or milestone required

ICD ACCEPTANCE

Released for commissioning: _________________________________ Date: ______________
(Commissioning Manager)

Appendix V

SAMPLE COMMISSIONING COMPLETION/AVAILABLE FOR SERVICE WALKDOWN CHECKLIST AND DECLARATION

V.1. SAMPLE COMMISSIONING COMPLETION/AVAILABLE FOR SERVICE WALKDOWN CHECKLIST

<table>
<tr><td colspan="4">SECTION A: GENERAL INFORMATION</td></tr>
<tr><td colspan="2">System walkdown date:</td><td colspan="2">Unit:</td></tr>
<tr><td colspan="4">System title:</td></tr>
<tr><td colspan="2">System No.:</td><td colspan="2">Associated system Nos:</td></tr>
<tr><td colspan="2">Master modification No.:</td><td colspan="2">Discipline modification Nos:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>System was:</td><td colspan="3">☐ Maintained in service with no modifications or major component replacements
☐ Kept in lay-up or shutdown state
☐ Modified/new</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Walkdown type:</td><td colspan="3">☐ Partial walkdown
☐ Final walkdown</td></tr>
<tr><td colspan="2"></td><td>Name</td><td>Initials</td></tr>
<tr><td rowspan="9">Walkdown participant(s):</td><td>☐ Commissioning</td><td></td><td></td></tr>
<tr><td>☐ Maintenance</td><td></td><td></td></tr>
<tr><td>☐ Operations</td><td></td><td></td></tr>
<tr><td>☐ Engineering</td><td></td><td></td></tr>
<tr><td>☐ Design</td><td></td><td></td></tr>
<tr><td>☐ Others:</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="4">Operations review:</td></tr>
</table>

Item No.	Operations to review the following	Acceptable (Y/N)	Comments
	Equipment tagging and labelling is acceptable (matches operational flowsheets; position assured components identified, temporary tags removed)		
	Operational flowsheets match physical field equipment		
	Power supply and air supply lists updated to allow for system operation		
	Housekeeping of area is acceptable		
	System is accessible, operable, and has no error-likely situations or safety concerns		
	System is aligned correctly		
	Maintenance to review the following	**Acceptable (Y/N)**	**Comments**
	Housekeeping of area is acceptable		
	System is accessible, operable, and has no error-likely situations or safety concerns		
	No fluid or gas leaks seen (visual and auditory checks)		
	Temporary grounds have been removed and all permanent grounds have been installed		
	Worker protection has been removed to support system operation		

	Engineering to review the following	Acceptable (Y/N)	Comments
	System performance monitoring and surveillance plans updated to reflect new system		
	Construction labelling and field aids removed		
	Enterprise system master equipment lists are up to date		
	No abnormal noise, vibrations, leaks, alarms or environmental conditions observed		
	System parameters are within expected range		
	System fire or radiation barriers are in place		
	Material condition satisfactory (no observed loose material, corrosion, bent or damaged supports)		
	Access platforms, structures around equipment are in good condition		

Walkdown items to be addressed:

Item No.	Description	Reference (post-walkdown)	AFS related (Y/N) (Y=must be addressed prior to AFS declaration)

V.2. SAMPLE COMMISSIONING COMPLETION/AVAILABLE FOR SERVICE DECLARATION

<table>
<tr><td colspan="4">SECTION A: GENERAL INFORMATION</td></tr>
<tr><td colspan="2">☐ Partial AFS or ☐ Final AFS</td><td colspan="2">Temporary modification: ☐ Yes or ☐ No</td></tr>
<tr><td colspan="2">Facility No.:</td><td colspan="2">Unit:</td></tr>
<tr><td colspan="2">Master modification No.: Revision No.:</td><td colspan="2">Discipline modification Nos and revision Nos:</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>System was:</td><td colspan="3">☐ Maintained in service with no modifications or major component replacements
☐ Kept in lay-up or shutdown state
☐ Modified/new</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Date of walkdown:</td><td colspan="3"></td></tr>
<tr><td rowspan="3">Walkdown participant(s):</td><td>☐ Commissioning
☐ Maintenance
☐ Operations
☐ Engineering
☐ Design
☐ Others:</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

AFS PACKAGE CONTENTS

Document	Title	Attached (Y/N)

SECTION B: DESIGN REVIEW AND DECLARATION

Issue	Yes/No/Not applicable	Description or comments
Commissioning test results have been reviewed by the design engineer and the modification meets the modification performance requirements and intent.		
All unresolved deviations from design requirements have been recorded and design authority has agreed on the path(s) forward.		
Enterprise master equipment database is ready for update/formal release.		
Abandoned and removed components identified to have status in enterprise master equipment database listed as RETIRED and REMOVED as applicable.		
Equipment bills of material in enterprise master equipment database are updated.		
Test report is written and accepted.		
Industrial safety pre-start health and safety review has been completed.		
Design verification of channelization and separation requirements for all modification packages has been completed.		
All required pressure boundary classification and registration processes (as required) are completed.		
Wiring configuration programmes are up to date and reflect field conditions.		
Operations power and air supply list data are up to date and reflect field conditions.		
Equipment qualification assurance process is complete.		
Constructability, operability, maintainability and safety concerns raised have been addressed in the design.		

AFS recommended by design responsible engineer:

________________	_________________________	_________________
Name	**Signature**	**Date (YYYY-MM-DD)**

SECTION C: SYSTEM ENGINEER REVIEW AND DECLARATION

Issue	Yes/No/Not applicable	Description or comments
Surveillance requirements for system are incorporated into system monitoring plans.		
Revisions to operating and maintenance documentation and inspection instructions or procedures have been reviewed and determined to be within the safe operating envelope.		
Maintenance call-ups are in place or scheduled for implementation prior to need.		
Operational flowsheet has been revised and issued.		
Scope of modification has been reviewed and it has been determined if components need to be added or removed from the ageing management database. Results of determination have been communicated to and accepted by the engineer(s) responsible for the component.		
Modification has been reviewed and impact(s) on periodic inspection programmes have been identified, and necessary inaugural or periodic inspections have been completed.		
Material condition is acceptable and no abnormal field conditions or alarms are observed. Constructability, operability, maintainability and safety concerns raised have been addressed.		

AFS recommended by system responsible engineer:

________________	_________________________	_________________
Name	**Signature**	**Date (YYYY-MM-DD)**

SECTION D: CONSTRUCTABILITY ISSUE REVIEW AND DECLARATION

Issue	Yes/No/Not applicable	Description or comments
Open items have been all been appropriately resolved, with the disposition appropriately recorded, or with action through a corrective action programme to resolve them by an appropriate date or milestone. Open item list is attached.		
It has been confirmed that inspection and test plans incorporate requirements of latest design revisions (including field changes).		
Equipment and components have been installed according to latest design modification revisions (including field changes).		
Required quality checks are complete and acceptable.		
Equipment, including abandoned equipment, is properly labelled.		
Equipment and components have been installed and commissioned in accordance with applicable codes, standards and regulations.		
Constructability, operability, maintainability and safety concerns raised have been addressed.		

AFS recommended by commissioning responsible engineer:

______________ ______________________ ________________

Name **Signature** **Date (YYYY-MM-DD)**

SECTION E: OPERABILITY ISSUE REVIEW AND DECLARATION

Issue	Yes/No/Not applicable	Description or comments
New, modified or abandoned systems, structures and components meet operability, accessibility and safety requirements.		
Systems or equipment is in operational status, including required mock-ups.		
Open items do not impede operations.		
Housekeeping is acceptable.		
Operating documentation (including operational flowsheet and engineered tool calibration procedures) is accepted and available for use.		
Field labelling of new, modified or abandoned equipment is in place and acceptable. Position assured component lists have been updated.		
Trained operators are available.		
Operating call-ups and surveillance routines are in place or scheduled for implementation prior to need.		
Constructability, operability, maintainability and safety concerns raised have been addressed.		

AFS recommended by operations representative:

______________ ______________________ ________________

Name **Signature** **Date (YYYY-MM-DD)**

SECTION F: MAINTENANCE ISSUE REVIEW AND DECLARATION		
Issue	**Yes/No/Not applicable**	**Description or comments**
Modification meets maintainability and safety requirements.		
Material condition is acceptable. No visible or audible fluid or gas leaks.		
Open items do not impede maintenance.		
Maintenance and vendor documentation is accepted and available for use at time of signature.		
Trained maintainers are available.		
Maintenance strategy has been developed.		
Maintenance call-ups are in place or scheduled for implementation prior to need.		
Constructability, operability, maintainability and safety concerns raised have been addressed.		

AFS recommended by maintenance representative:

Name	**Signature**	**Date (YYYY-MM-DD)**

SECTION G: DECLARATION OF AVAILABILITY FOR SERVICE

AFS recommended by design authority

Name	**Signature**	**Date (YYYY-MM-DD)**

AFS accepted by operations authority

Name	**Signature**	**Date (YYYY-MM-DD)**

Appendix VI

SAMPLE COMMISSIONING SPECIFICATION

This appendix contains excerpts from a sample commissioning specification used to document commissioning requirements of an auxiliary power system at a Canadian NPP. It can be adapted and used as a template for similar commissioning specifications. Item numbering and some other minor changes have been made for clarity. In this context, a complete design package is referred to as a design change package (DCP), while an individual discipline-specific subpackage (e.g. electrical, mechanical, I&C or civil) is referred to as a design change notice (DCN).

Section VI.2 documents the objectives of the commissioning activities, in this case to demonstrate that a number of modifications made meet their commissioning specification requirements. Section VI.3 documents the system's performance requirements under standard operating conditions that needed to be proven, with reference to the standard, procedure, drawing or other source from which the requirement was derived. Note that some requirements from the original specification in Section VI.3.2 are not shown.

VI.1. SCOPE

This detailed commissioning specification covers the overall commissioning of the auxiliary power system (APS). This covers the required testing and commissioning to demonstrate that the APS system meets all the requirements specified in the documents listed in Table 5.

TABLE 5. MODIFICATIONS WITHIN SCOPE

DCP No.	DCN No.	Discipline	SCI[a]	System name	Title
83037 (non-safety related)	84977	Electrical	53200	4 kV distribution system	Cable terminations between new site electrical system (SES) bus breakers and outside the protected area; terminal point (non-safety related)
	84976	Electrical	57000	Cable, conduit and cable pans	Cable trays between new SES bus breakers and outside the protected area; terminal point (non-safety related)
	87907	Electrical	57000	Cable, conduit and cable pans	MCR modification: addition of fibre optic cables
	85140	Civil	22259	Steelwork — miscellaneous	Cable support between new SES bus breakers and outside the protected area; terminal point (non-safety related)
	85038	Civil	29941	Concrete and reinforcing steel — substructure	Miscellaneous concrete tab to bus duct (non-safety related)
	88170	I&C	65320	4 kV distribution system	058-50000 — Auxiliary power system

TABLE 5. MODIFICATIONS WITHIN SCOPE (cont.)

DCP No.	DCN No.	Discipline	SCI	System name	Title
	84981	Electrical	53200	4 kV distribution system	Installation of new breaker CB1XE and control
	84982	Electrical	53200	4 kV distribution system	Installation of new breaker CB1XF and control
	84999	Electrical	57000	Cable, conduit and cable pans	Control and monitoring cables MCR to fibre optic interface cabinets, 48 V DC panels and to 058-53200-CB1XE/CB1XF
83035 (safety related)	85000	Electrical	67140	Fire protection	Installation of fire detectors, cables and conduits, and fire panel modification for breakers CB1XE and CB1XF
	85001	I&C	66100	MCR panels and furniture	058-66100 — MCR control logic
	85032	Electrical	58120	Grounding — equipment connection	Grounding of equipment (safety related)
	85034	Electrical	57000	Cable, conduit and cable pans	Cables and cable terminations (safety related)

[a] SCI — system commissioning index.

VI.2. COMMISSIONING OBJECTIVES

The following are the objectives of this detailed commissioning specification (DCS):

— Verify that permanent modification (PMOD) for the APS has been installed and commissioned as per the DCNs listed in the safety related DCP 83035 and the non-safety related DCP 83037.
— Verify that commercial modification (CMOD) for the APS has been installed and commissioned as per the DCNs.
— Verify that the APS has been commissioned and meets the requirements as specified in the design requirements P-DR-50000-00001 (System Design Manual Part 1 and System Design Requirements).

Note:

(a) The 230 kV will be commissioned by DCS NK30-DCS-51300-00001.
(b) The fire protection system modification commissioning is covered under NK30-DCS-67140-00003.
(c) The APS power plant will be commissioned by the joint venture AMEC/Black and McDonald.

VI.3. PERFORMANCE REQUIREMENTS: STANDARD OPERATING CONDITIONS

VI.3.1. Equipment control logic

— Verify that the 48 V DC transfer relay functions as per design specifications.
- Reference: NK30-DRAW-66100-10015 (Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram).

— Verify the control panel and wiring in the main control room and control equipment room are installed and function as per design.
  - Reference: DCN 85001; NK30-DRAW-66100-10015 (Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram).

— Verify fibre cable links between the APS systems are installed and function as per design.
  - Reference: DCN 88170; NK30-DRAW-65320-10008 (APS SES Connection Fibre Optic Interface Functional Block Diagram); NK30-DRAW-65320-10009 (APS SES Connection Fibre Optic Interface Elementary Wiring Diagram); A1-150325-10 (Auxiliary Power Plant — Control System — Wiring Diagram — Media Converter).

— Verify MCR hand switch operation of the 4 kV breakers 058-53200-CB1XE and -CB1XF.
  - Reference: NK30-DRAW-66100-10015 (Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram).
  - Jumpers need to be applied at panels 058-65498-AJB-05 and 058-65498-AJB-02 (see A1-150325-10 (Auxiliary Power Plant — Control System — Wiring Diagram — Media Converter)).

VI.3.2. Equipment performance parameters

— Verify that cable pans and risers have been properly grounded as per N-INS-01983.4-10019 (Cable Pan and Cable Pan Riser Inspection) for the following sections of cable pan and cable pan risers.

Cable pan/riser inspections	
a	East Annex portion (vertical section from duct bank to 294 ft elevation penetration)
b	294 ft elevation run from U8 turbine auxiliary bay (TAB) exterior wall to new switchgear (058-53200-CB1XE/CB1XF)
c	Between 058-53200-CB1XE/CB1XF and 8-53200-BUAE/BUCF extension cabinets

— Verify minimum insulation resistance on the 4 kV termination boxes at the outfall is as per P-AB-CMP-50000.11 (Insulation Tests with Megger and Minimum Insulation Resistance) for the termination boxes listed below.

Termination boxes Megger test	
a	058-53200-JB5411
b	058-53200-JB631

— Ensure that the voltage is 48 ± 10% V DC (43.2–52.8V DC) for the following as per P-AB-CMP-50000.88 (load verification).

[Some other requirements from the original specification are not shown.]

VI.3.3. Interaction with interfacing systems

— Verify that a functional/trip test of the SES bus protective relays is performed to demonstrate operation of the 058-53200-CB1XE/CB1XF breakers. Reference SES tie-in work plans NK30-WPL-53200-0192213/-0192214.

VI.3.4. Tolerance for normal process variations

— Not applicable for this modification.

VI.3.5. Set point correctness and tolerance

— Verify that protection trip relays are tested as per work plans NK30-WPL-53200-0192213/-0192214 appendix C.

VI.4. PERFORMANCE REQUIREMENTS: NON-STANDARD OPERATING CONDITIONS

VI.4.1. Subject SSC failure modes

— Verify that during the high pressure emergency coolant injection (HPECI) pump test, the voltage will stabilize within 7 seconds after the HPECI pump starts.
- Reference: Generally accepted tolerance for power supplies.

— Verify that during the heat transport (HT) pump test (2-0 configuration), the voltage will stabilize within 40 seconds after the HT pumps start as long as the HT pumps do not trip.
- Reference: Generally accepted tolerance for power supplies.

VI.4.2. Design basis accidents

— Verify the timing for Unit 5 authorized nuclear operator to establish the APS power supply to the SES bus and start an HPECI pump via the APS. (The DR specifies that an HPECI pump can be started within 30 minutes of a station loss of class IV power with power supplied to the SES bus via the APS.)
- Reference: P-DR-50000-00001.

VI.5. OTHER REQUIREMENTS

VI.5.1. Pre-outage commissioning activities

NOTE
This section applies to the work done before the SES tie-in outages and the HPECI commissioning test.

— Verify that all items listed in the “Compensatory Measures to Improve Performance of Plant Modifications When Full Commissioning is Not Possible or Practicable” are completed.
- Reference: Memo attached — Attachment A.

— Verify that the phase rotation at 058-53200-CB1XE/CB1XF matches APS power plant AND Pickering B as per N-INS-01983.4-10006.

VI.5.2. Authorized inspection agency (AIA) notification requirements

— Not applicable for this modification.

VI.5.3. Acceptable personal safety

— Verify correct nomenclature labels are installed on each device (termination boxes, switchgear, etc.).
— Verify warning labels installed for the appropriate voltage level on each device (termination boxes, switchgear, etc.).

VI.5.4. Feasibility of reliability programme

— Not applicable for this modification.

VI.5.5. Feasibility of routine maintenance

— Not applicable for this modification.

VI.5.6. Special system tests

— Not applicable for this modification.

VI.5.7. Other SSCs affected by modification

— Not applicable for this modification.

VI.5.8. System line-up following completion of commissioning

— Verify that breakers 058-53200-CB1XE and 058-53200-CB1XF have been left open after SES tie-ins and HPECI pump test run.
- Reference: not applicable.

VI.6. REFERENCES

— P-DR-50000-00001 Auxiliary Power System (System Design Manual Part 1, System Design Requirements).
— APS installation work plans are shown in Table 6.

TABLE 6. APS INSTALLATION WORK PLANS

Work plan No.	Work order No.	Title
NK30-WPL-53200-0185521	1361533	4.16 kV CMOD
NK30-WPL-29900-0185522	1361534	Security Penetration
NK30-WPL-53200-0185523	1361536	4.16 kV PMOD
NK30-WPL-66100-0185524	1361537	MCR Modifications
NK30-WPL-67140-00001	1361539	Fire Protection Modifications

— APS tie-in and commissioning work plans are shown in Table 7.

TABLE 7. APS TIE-IN AND COMMISSIONING WORK PLANS

Work plan No.	Work order No.	Title
NK30-WPL-53200-0192212	1318324	APS Pre-Tie-In Testing and Commissioning
NK30-WPL-53200-0192213	1361540	APS SES-BUE Tie-In
NK30-WPL-53200-0192214	1361541	APS SES-BUF Tie-In
NK30-WPL-54900-0217347	1361532	APS Commissioning — Full Load Testing via Grid
NK30-WPL-53200-0192215	1361542	APS HPECI Commissioning Test
NK30-WPL-53200-0192216	1400053	APS HT Commissioning Test

VI.7. ATTACHMENTS TO COMMISSIONING SPECIFICATION

VI.7.1. Attachment A: Compensatory Measures to Improve Performance of Plant Modification When Full Commissioning Is Not Possible or Practical

Auxiliary Power System
4 kV (SES) Connection
Permanent Modification (PMOD)

MODIFICATION REFERENCES: DCP Nos 83035 AND 83037

If the modification above cannot be fully commissioned to confirm compliance with design requirements, the following process will be applied per Chief Nuclear Engineer Directive No. 05-01 as a means of demonstrating due diligence.

This form is to be used throughout the modification implementation process and upon completion, filed with the modification package as documentary proof of compliance with the noted Directive.

Accountabilities		
1	Individual responsible for the design quality assurance program per CSA N286	Design Team Leader (DTL)
2	Individual responsible for ensuring field installation conforms to the design (note: any deviation must be reviewed and signed off by the design authority)	Field Team Leader (Installation) (FTL(I))
3	Individual responsible for testing and commissioning for the modification	Modification Team Leader (MTL)

Critical attributes			
Have critical attributes been assessed by an independent party and documented? The critical attributes for the modifications under DCP Nos 83035 and 83037 are listed below. Only those critical attributes that impact designs that are considered non-standard or for which the company does not have the specific expertise will be subjected to an independent party verification.			
No.	Critical attribute	Method of verification	Accepted by
1	**Duct bank rebar** The rebar in the duct bank to be installed under the security fence must not form a continuous loop around power cables as required by design. Failure to comply with the design would result in eddy current heating of the rebar when the APS is in mission. The heating of the rebar would not allow normal cable heat to be dissipated through the duct bank to the earth. This has the potential to permanently damage the power cables.	The items listed below shall be inspected prior to placement of formwork and pouring of concrete. The bracketed number refers to the relevant section of specification NK30-TS-29941-00001. — Rebar placement (8.5.6.1); — Embedded parts (8.6.6.2).	FTL(I)
2	**Electrical grounding system** The trays and supports provide a conductive pathway between the station SES buses and the 4 kV APS buses. The grounding system ensures that the potential rise is adequately dissipated for the protection of personnel.	The items listed below shall be inspected to ensure: — Power cables are grounded in accordance with NK30-DES-58100-0001 (4.3.1a and b). — Power cable shields are grounded at the source end only and the other end is insulated to prevent contact with metallic surfaces (4.3.1c). — Cable trays are grounded in accordance with NK30-DES-58100-0001 (4.6.1.2). — Transitions from trays to conduit have continuous grounding in accordance with: • NK30-DES-58100-0001; • NK30-DES-57000-0001 and 0002; • NK30-DBS-57000-0017; • (4.6.2g). — 4 kV and 600 V equipment is provided with two grounds (4.11.1). — Conduits are grounded using locknuts and bushings and grounding type bushings are used on runs over 25 feet (4.11.1). — Instrument panels are grounded with at least #4 wire to the nearest station ground or are solidly welded to grounded steel structures (4.11.2a). — All accessible miscellaneous steel that is not secured to building main structures (e.g. handrails) is grounded with #2/0 wire (4.11.4). — Pull boxes are grounded via conduit/locknut. The above bracketed number refers to the relevant section of specification P-INS-01983.4-00009.	FTL(I)

3	**Cable support structure on East Annex roof** The APS cable support structures are designed to function in an ice storm and to be more robust than the transmission system. CSA 22.1 requires the design of transmission towers to allow 1 ¼ in. to 1 ½ in. of radial ice accumulation. The APS design allows 2 in. Further, the APS cable support structures are common for the odd and even trains. Failure of the structure would result in the unavailability of the entire system. The quality of steel fabrication process, connections to East Annex structures and foundations are critical.	A. Prefabricated steel component The items listed below shall be inspected and/or reviewed prior to fabrication or erection of prefabricated steel structures: — Mill and galvanizing test reports (2.5.2); — Shop welding and inspection procedures and welder qualifications (3.3.1.3m); — Connection designs (3.3.3a); — Shop inspection prior to shipment (3.5.1); — Shop submittals (3.6.1); — Field welding and inspection procedures and welder qualifications (4.3.3f); — Fastener torque and inspection procedures (4.3.3h); — Proposed column base plate grouting sequence, scheduling and means of grouting (4.3.5d). The above bracketed number refers to the relevant section of specification NK30-TS-24259-00001. B. Foundation component The items listed below shall be inspected and/or reviewed prior to backfilling and pouring of concrete: — Granular backfill material sieve analysis (A.1.5.1); — Form coatings, sealers and release agents (A.3.4.3); — Rebar material mill test report or certificate of conformance (A.4.4.1); — Rebar support, ties, chairs and spacers (A.4.4.2); — Embedded part supports (A.5.4.2); — Use of curing compound (A.6.4.2); — Granular backfill compaction (B.2.6.1); — Layers of filter materials for drainage pipes shall not exceed 150 mm (6 in) (B.3.5 and B.3.6); — Formwork inspection before pour (B.4.6); — Formwork removal after pour (B.4.6); — Rebar placement before placement of formwork and pouring concrete (B.5.6.1); — Embedded parts inspection (B.6.6.2); — Concrete curing method (B.7.5.6.2); — Cold weather curing time (B.7.5.6.3d); — Determine if hot weather curing is required (B.7.5.6.4.1); — Repair of concrete defects (B.7.5.7); — Concrete delivery sampling and testing (B.7.6.2.1): • Compression tests (B.7.6.2.3); • Slump tests (B.7.6.2.4); • Air contents tests (B.7.6.2.5); • Core tests (B.7.6.2.6); • Non-destructive tests (B.7.6.2.7); The above bracketed number refers to the relevant section of specification NK30-TS-29941-00001.	DTL for items: A1, A3, A5, A8, B1, B2, B3, B4, B5, B6, B7, B10, B13, B14, B15, B16, B17 FTL(I) for items: A2, A4, A6, A7, B8, B9, B11, B12

4	**Environmentally qualified barrier penetrations** The APS protection and control cables that route between the Unit 8 TAB area and the Main Control Room/ Control Equipment Room will penetrate the 294 ft 0 in. elevation floor. This floor is a credited environmentally qualified steam barrier. Listed below are the cable numbers and penetration grid location. At grid location M-152: 5-30782, 5-30783, 5-40968, 5-40969 At grid location H-137: 8-78179, 8-78181, 8-78183, 8-78185, 8-78187 At grid location M-141: 8-78180, 8-78182, 8-78184, 8-78186, 8-78188	Each cable penetration shall be sealed with material as described by catalog number 328960, in accordance with the following documents: NK30-TSC-22030-00001 Fire and Steam Barrier Installation and Repair, section 4.4 caulk installation. Sections 4.1.7, 4.1.8, 4.2.6, 4.4.2 and 4.4.3. P-INS-01983.4-00009 Electrical Installation Specifications, sections 4.5.2.2a, 4.5.2.3a., 4.5.2.3b, 4.5.2.3d, 4.5.2.4l, 4.5.2.5a, 4.5.2.5b and 4.5.2.5c. 1. Install drop cloths or protective coverings where necessary to protect adjacent surfaces and/or equipment from possible damage by debris. 2. Ensure damming materials are installed prior to applying sealant. 3. Remove any foreign objects or combustible materials from penetration opening. 4. The penetration substrate surface and also the penetrating medium shall be clean, dry and free of all deleterious materials. Loose rust and mill scale shall be removed, where possible, by wire wheel, sanding or other method that will not damage penetrating items. Do not use alcohol to clean surfaces in the penetration opening. Alcohol can keep sealant from curing properly. Recommended cleaning solvents are xylene, toluene or methyl ethyl ketone to clean the intended seal area to remove pulling compound and other residue, as required. 5. Verify that caulk is within shelf life. Ensure the sealant has been adequately stored at room temperature of not less than 32°F and not more than 92°F. 6. If electrical cables are present, then taking special care, separate cables to the extent possible to facilitate complete encapsulation of cables. 10 mm spacing is considered adequate. 7. Ensure sealant cures for at least 24 hours prior to removing damming material. 8. Inspect seal after 24 hours of curing for tightness. 9. If required, apply additional sealant. Reinspect seal upon another 24 hour cure time. NK30-TSC-22030-00001 Technical Specification for Steam Barriers, Sealing of Small Openings — PNGS B appendix A, B and D. Appendix F Location of Openings, Size and Seal Types will be updated as required.	FTL(I)

Rigour of constructability, operability, maintainability and safety (COMS) review and available for service process		
1	Have enhanced COMS meetings been completed with appropriate level of due diligence?	Yes. Stratum III and IV management were involved in each of the scoping and final COMS.
2	Have enhanced AFS meetings been completed with appropriate level of due diligence?	DTL to sign off on inspection and test plans.

Field verification of design		
1	Has field installation been completed consistent with the design by qualified staff?	FTL(I) to confirm at AFS stage

2	Has field installation been independently verified to be consistent with the design by qualified staff?	MTL to confirm at AFS stage
3	Do testing and/or inspection confirm all critical attributes have been addressed?	DTL to confirm at AFS stage
4	Was the quality of the testing and/or inspections consistent with that of Field Engineering Inspection and Test Plans?	FTL(I) to confirm at AFS stage

Note:

— Accountable individuals are expected to be present at COMS and AFS meetings to ensure appropriate levels of due diligence are applied. Where they are not present, meetings will be cancelled, a station condition record or non-conformance report raised and appropriate line managers informed of the situation.
— Any exceptions or deviations from this directive require written approval from the CNE.
— Per attached memorandum to file NK30-GEN-54900-7 entitled "Auxiliary Power System (APS) AFS Strategy", SES bus E will be placed in service without having run an electrical load through the breaker. This configuration will remain for about an 8 week window to allow the project to declare both SES buses E and F available to support all loads, with the exception of forced circulation cool down, in the unlikely event of a loss of bulk electrical system (LOBES). The risk associated with this strategy is acceptable because all commissioning will be complete prior to placing bus E in service. Please see the referenced memo attached for the rationale associated with this proposed strategy.

Accountabilities		**Design (DCP) stage**	**AFS stage**
Prepared by	MTL	Name and signature/date	
Reviewed by	FTL(I)	Name and signature/date	
Reviewed by	DTL	Name and signature/date	
Approved by	Design Authority	Name and signature/date	

Appendix VII

SAMPLE TEST REPORT

The following are excerpts from a sample test report used to document successful commissioning of an auxiliary power system at a Canadian NPP. The report corresponds to the commissioning specification that was presented in Appendix VI. It can be adapted and used as a template for similar test reports. Item numbering and some other minor changes have been made for clarity.

Section VII.2 documents the main objective of the commissioning activities, in this case to demonstrate that a number of modifications made meet their commissioning specification requirements. Section VII.3 documents the system's performance requirements under standard operating conditions that needed to be proven, and the work instruction (called 'work plans' at this company) that confirmed that this requirement was met. Note that some requirements from the original specification in Section VII.3.2 are not shown. In addition, some of the figures in the original report relating to the heat transport tests are not shown here.

VII.1. SCOPE

This test report covers commissioning of the modifications (DCNs) identified in Table 8, and all required testing and commissioning to demonstrate that the applicable parts of the APS meet the requirements specified in the documents noted.

TABLE 8. MODIFICATIONS WITHIN SCOPE

DCP No.	DCN No.	Discipline	SCI[a]	System name	Title
83037 (non-safety related)	84977	Electrical	53200	4 kV distribution system	Cable terminations between new SES bus breakers and outside the protected area; terminal point (non-safety related)
	84976	Electrical	57000	Cable, conduit and cable pans	Cable trays between new SES bus breakers and outside the protected area; terminal point (non-safety related)
	87907	Electrical	57000	Cable, conduit and cable pans	MCR modification: addition of fibre optic cables
	85140	Civil	22259	Steelwork — miscellaneous	Cable support between new SES bus breakers and outside the protected area; terminal point (non-safety related)
	88170	I&C	65320	4 kV distribution system	058-50000 — Auxiliary power system

TABLE 8. MODIFICATIONS WITHIN SCOPE (cont.)

DCP No.	DCN No.	Discipline	SCI	System name	Title
83035 (safety related)	84981	Electrical	53200	4 kV distribution system	Installation of new breaker CB1XE and control
	84982	Electrical	53200	4 kV distribution system	Installation of new breaker CB1XF and control
	84999	Electrical	57000	Cable, conduit and cable pans	Control and monitoring cables MCR to fibre optic interface cabinets, 48 V DC panels and to 058-53200-CB1XE/CB1XF
	85001	I&C	66100	MCR panels and furniture	058-66100 — MCR control logic
	85032	Electrical	58120	Grounding — equipment connection	Grounding of equipment (safety related)
	85034	Electrical	57000	Cable, conduit and cable pans	Cables and cable terminations (safety related)

[a] SCI — system commissioning index.

VII.2. COMMISSIONING OBJECTIVE

The objective of commissioning is to demonstrate that the modifications completed as per DCNs 84977, 84976, 87907, 85140, 88170, 84981, 84982, 84999, 85001, 85032 and 85034 of DCP Nos 83035 and 83037 meet the requirements set out in DCS NK30-DCS-50000-00001.

VII.3. PERFORMANCE REQUIREMENTS: STANDARD OPERATING CONDITIONS

VII.3.1. Equipment control logic

— Verify that the 48 V DC transfer relay functions as per design specifications.
- Reference: NK30-DRAW-66100-10015 (Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram).

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 6.0	Complete

— Verify the control panel and wiring in the MCR and control equipment room are installed and function as per design.
- Reference: DCN 85001; NK30-DRAW-66100-10015 (Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram).

Disposition		Status
a	Work plan NK30-WPL-53200-0192212, section 6.0	Complete
b	Work plan NK30-WPL-66100-185524	Complete

— Verify fibre cable links between the APS systems are installed and function as per design.
  - Reference: DCN 88170; NK30-DRAW-65320-10008 (APS SES Connection Fibre Optic Interface Functional Block Diagram); NK30-DRAW-65320-10009 (APS SES Connection Fibre Optic Interface Elementary Wiring Diagram); A1-150325-10 (Auxiliary Power Plant – Control System – Wiring Diagram – Media Converter).

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 6.0	Complete

— Verify MCR hand switch operation of the 4 kV breakers 058-53200-CB1XE and -CB1XF.
  - Reference: NK30-DRAW-66100-10015 - "Main Control Room Remote Status of APS Equipment in MCR Elementary Wiring Diagram".

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 6.0	Complete

VII.3.2. Equipment performance parameters

Verify that cable pans and risers have been properly grounded as per N-INS-01983.4-10019 (Cable Pan and Cable Pan Riser Inspection) for the following sections of cable pan and cable pan risers.

Cable pan/riser inspections	
a	East Annex portion (vertical section from duct bank to 294 ft elevation penetration)
b	294 ft elevation run from U8 TAB exterior wall to new switchgear (058-53200-CB1XE/CB1XF)
c	Between 058-53200-CB1XE/CB1XF and 8-53200-BUAE/BUCF extension cabinets

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 4.1.1	Complete

— Verify minimum insulation resistance on the 4 kV termination boxes at the outfall is as per P-AB-CMP-50000.11 (Insulation Tests with Megger and Minimum Insulation Resistance) for the termination boxes listed below.

Termination boxes Megger test	
a	058-53200-JB5411
b	058-53200-JB631

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 4.2.3	Complete

— Ensure that the voltage is 48 ± 10% V DC (43.2–52.8 V DC) for the following as per PAB-CMP-50000.88 (load verification).

48 V DC load verification	
a	Odd wiring: 058-55200-PL7809 (APS Power Plant) to 058-55200-JB5414 (Termination Box) to 058-55200-PL5419 (294 ft elevation)
b	Even wiring: 058-55200-PL7808 (APS Power Plant) to 058-55200-JB6319 (Termination Box) to 058-55200-PL6545 (294 ft elevation)

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 5.1	Complete

VII.3.3. Interaction with interfacing systems

— Verify that a functional/trip test of the SES bus protective relays is performed to demonstrate operation of the 058-53200-CB1XE/CB1XF breakers. Reference SES tie-in work plans NK30-WPL-53200-0192213/-0192214.

Disposition		Status
a	Work plan NK30-WPL-53200-0192213, section 5.5	Complete
b	Work plan NK30-WPL-53200-0192214, section 5.5	Complete

VII.3.4. Tolerance for normal process variations

— Not applicable for this modification.

VII.3.5. Set point correctness and tolerance

— Verify the protection trip relays are tested as per work plans NK30-WPL-53200-0192213/-0192214 appendix C.

Disposition		Status
a	Work plan NK30-WPL-53200-0192213, appendix C	Complete
b	Work plan NK30-WPL-53200-0192214, appendix C	Complete

VII.4. PERFORMANCE REQUIREMENTS: NON-STANDARD OPERATING CONDITIONS

II.4.1. Subject SSC failure modes

— Verify that during the HPECI pump test, the voltage will stabilize within 7 seconds after the HPECI pump starts.
  - Reference: Generally accepted tolerance for power supplies.

Disposition	Status
Work plan NK30-WPL-53200-0192215, section 5.6.6	From the Yokogawa Chart recorder, during the HPECI pump test, the voltage stabilized within 3.084 seconds. Refer to Figs 27 and 28 for the voltage profile and time. Complete

— Verify that during the heat transport (HT) pump test (2-0 configuration), the voltage will stabilize within 40 seconds after the HT pumps start as long as the HT pumps do not trip.
  - Reference: Generally accepted tolerance for power supplies.

Disposition	Status
Work plan NK30-WPL-53200-0192216, section 4	The voltage from the first set of 2 HT system pumps stabilized 17.618 seconds after starting and the voltage from the second set of 2 HT system pumps stabilized 20.144 seconds after starting. Refer to work plan NK30-WPL-53200-0192216 and NK30-CALC-50000-00005 for other results. Complete

VII.4.2. Design basis accidents

— Verify the timing for Unit 5 ANO to establish the APS power supply to the SES bus and start an HPECI pump via the APS. (The DR specifies that an HPECI pump can be started within 30 minutes of a station loss of class IV power with power supplied to the SES bus via the APS.)
  - Reference: P-DR-50000-00001.

Disposition	Status
Work plan NK30-WPL-53200-0192215, section 5	During the HPECI pump test, the combustion turbine unit (CTU) was started from the MCR push button on PL1D (4 minutes 40 seconds for the CTU to run up to full speed), then the SES 5320-BUF was isolated (during a LOBES, the SES 5320-BUF would be dead and this would not be a requirement to isolate the bus), then the HPECI pump was started. From the above, the overall time was 30 minutes 40 seconds. This time includes verifying voltages in the field at the SES breakers. Complete

VII.5. OTHER REQUIREMENTS

VII.5.1. Pre-outage commissioning activities

> **NOTE**
> This section applies to the work done before the SES tie-in outages and the HPECI commissioning test.

— Verify that all items listed in the “Compensatory Measures to Improve Performance of Plant Modifications When Full Commissioning is Not Possible or Practicable” are completed.

- Reference: Memo attached — Attachment A.

Disposition	Status
Refer to inspection and test plans identified in Attachment B.	Complete

— Verify that the phase rotation at 058-53200-CB1XE/CB1XF matches APS power plant and Pickering B as per N-INS-01983.4-10006.

Disposition	Status
Work plan NK30-WPL-53200-0192212, section 9.1.3. The phases were checked and the phase rotation will be checked before the HPECI test.	Complete

VII.5.2. Authorized inspection agency (AIA) notification requirements

— Not applicable for this modification.

VII.5.3. Acceptable personal safety

— Verify correct nomenclature labels are installed on each device (termination boxes, switchgear, etc.).

Disposition	Status
Refer to inspection and test plans identified in Attachment B.	Refer to turnover records NK30-Q2-50000-Z-058-003 and NK30-Q2-50000-Z-058-002. Complete

— Verify warning labels installed for the appropriate voltage level on each device (termination boxes, switchgear, etc.).

Disposition	Status
Refer to inspection and test plans identified in Attachment B.	Refer to turnover records NK30-Q2-50000-Z-058-003 and NK30-Q2-50000-Z-058-002. Complete

VII.5.4. Feasibility of reliability programme

— Not applicable for this modification.

VII.5.5. Feasibility of routine maintenance

— Not applicable for this modification.

VII.5.6. Special system tests

— Not applicable for this modification.

VII.5.7. Other SSCs affected by modification

— Not applicable for this modification.

VII.5.8. System line-up following completion of commissioning

— Verify that breakers 058-53200-CB1XE and 058-53200-CB1XF have been left open after SES tie-ins and HPECI pump test run.
- Reference: n.a.

Disposition		Status
a	Work plan NK30-WPL-53200-0192213, section 5.5.20	Complete
b	Work plan NK30-WPL-53200-0192214, section 5.5.20	Complete
c	Work plan NK30-WPL-53200-0192215	Complete

VII.6. REFERENCES

— P-DR-50000-00001 Auxiliary Power System (System Design Manual Part 1, System Design Requirements).
— APS installation work plans are shown in Table 9.

TABLE 9. APS INSTALLATION WORK PLANS

Work plan No.	Work order No.	Title
NK30-WPL-53200-0185521	1361533	4.16 kV CMOD
NK30-WPL-29900-0185522	1361534	Security Penetration
NK30-WPL-53200-0185523	1361536	4.16 kV PMOD
NK30-WPL-66100-0185524	1361537	MCR Modifications
NK30-WPL-67140-00001	1361539	Fire Protection Modifications

— APS tie-in and commissioning work plans are shown in Table 10.

TABLE 10. APS TIE-IN AND COMMISSIONING WORK PLANS

Work plan No.	Work order No.	Title
NK30-WPL-53200-0192212	1318324	APS Pre-Tie-In Testing and Commissioning
NK30-WPL-53200-0192213	1361540	APS SES-BUE Tie-In
NK30-WPL-53200-0192214	1361541	APS SES-BUF Tie-In
NK30-WPL-54900-0217347	1361532	APS Commissioning — Full Load Testing via Grid
NK30-WPL-53200-0192215	1361542	APS HPECI Commissioning Test
NK30-WPL-53200-0192216	1400053	APS HT Commissioning Test

— APS post-commissioning tests/work plans are shown in Table 11.

TABLE 11. APS POST-COMMISSIONING TESTS/WORK PLANS

Work plan No.	Work order No.	Title
NK30-WPL-53200-0238318	1603024	Unit 4 Heat Transport Run from Auxiliary Power
NK30-WPL-54900-0295303	2051497	Auxiliary Power System Simulated LOBES Test

VII.7. ATTACHMENTS TO COMMISSIONING REPORT

VII.7.1. Attachment A: Compensatory Measures to Improve Performance of Plant Modification When Full Commissioning Is Not Possible or Practical

Accountabilities		**Design (DCP) stage**	**AFS stage**
Prepared by	MTL	Name and signature/date	Name and signature/date
Reviewed by	FTL(I)	Name and signature/date	Name and signature/date
Reviewed by	DTL	Name and signature/date	Name and signature/date
Approved by	Design Authority	Name and signature/date	Name and signature/date

VII.7.2. Attachment B: Listing of inspection and test plans (ITPs)

DCP/DCN	ITP	Description
83035/84981	NK30-Q2-53200-ITP-058-008 R00 NK30-Q2-53200-ITP-058-016 R00	CB1XE breaker and control
83035/84982	NK30-Q2-53200-ITP-058-010 R00 NK30-Q2-53200-ITP-058-017 R00	CB1XF breaker and control
83035/84999	NK30-Q2-66100-ITP-058-001 R05	CTU control MCR to terminal point
83035/85001	NK30-Q2-66100-ITP-058-002 R04	MCR logic control
83035/85032	NK30-Q2-58120-ITP-058-001 R05	Grounding
83035/85034	NK30-Q2-53200-ITP-058-011 R00	CB1XE/F CB21A/C pan/cable terminations
83037/84976	NK30-Q2-57000-ITP-058-001 R01 NK30-Q2-57000-ITP-058-003 R00	Cable tray SES bus breakers to terminal point
83037/84977	NK30-Q2-53200-ITP-058-007 R02 NK30-Q2-53200-ITP-058-009 R00	Cable terminations SES bus breakers to terminal point
83037/87907	NK30-Q2-53200-ITP-058-012 R03	Addition of fibre optic cables
83037/88170	NK30-Q2-53200-ITP-058-012 R03	APS safety related fibre optic
83035/83037	NK30-Q2-53200-ITP-058-015 R00	APS pre-SES tie-in testing and commissioning
83035/83037	NK30-Q2-53200-ITP-058-013 R00 BUE tie-in	BUE tie-in
83035/83037	NK30-Q2-53200-ITP-058-014 R00 BUF tie-in	BUF tie-in

VII.7.3. Attachment C: Data from HPECI test

Figure 25 shows the voltage profile from the HPECI test, and Fig. 26 shows the time required for the voltage to recover after the HPECI pump started. This test confirmed that the APS can supply the required power to start and operate a HPECI pump following a LOBES. The test was performed using 058-54900-CTG1 via SES bus BUF (reference work plan NK30-WPL-53200-0192215).

VII.7.4. Attachment D: Data from P761 — 2-0 heat transport test

Figure 27 shows the start time for the first set of 2 HT system pumps, and Fig. 28 shows the stop time. This test confirmed that the APS can supply the required power to start and operate the 4 HT system main circulating pumps required to operate the HT system in a 2-0/2-0 configuration following a LOBES. The test was performed using 058-54900-CTG2 via SES bus BUE (reference work plan NK30-WPL-53200-0192216).

VII.7.5. Attachment E: Data from P941 — 2-0 heat transport test

Figures 29–31 show results from the P941 — 2-0 heat transport test. In light of inter-station transfer bus voltage concerns, this test was performed to verify that the APS could operate the HT system at Unit 4 in a 2-0/2-0 configuration. The test was performed using 058-54900-CTG2 via SES bus BUE (reference work plan P-WPL-53200-0238318).

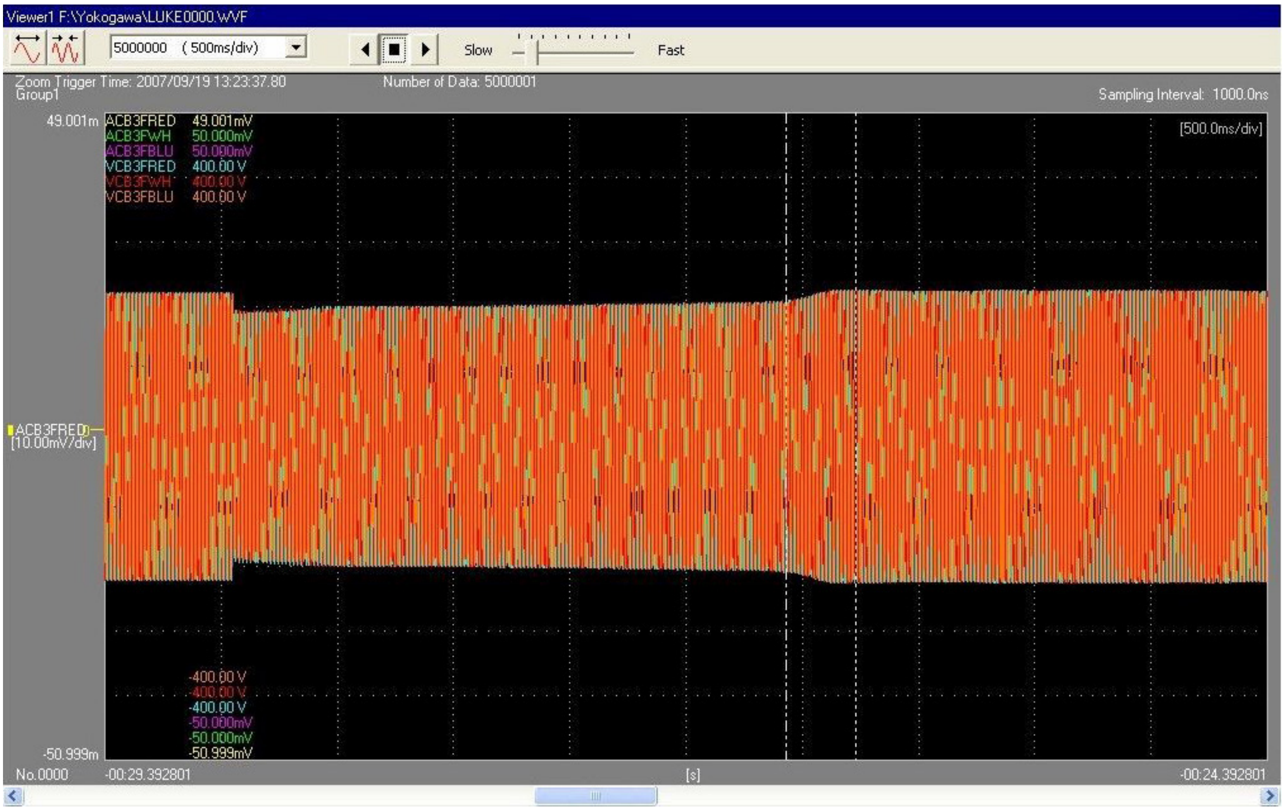


FIG. 25. Voltage profile for HPECI pump test.

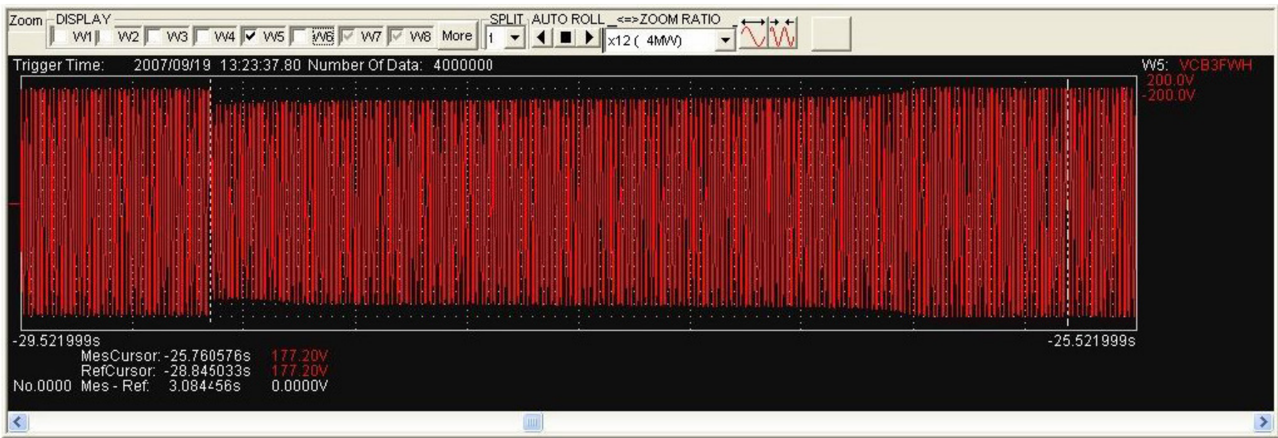


FIG. 26. Time for voltage to recover after HPECI pump started.

Start time for first set of 2 pumps 12:30:58.514

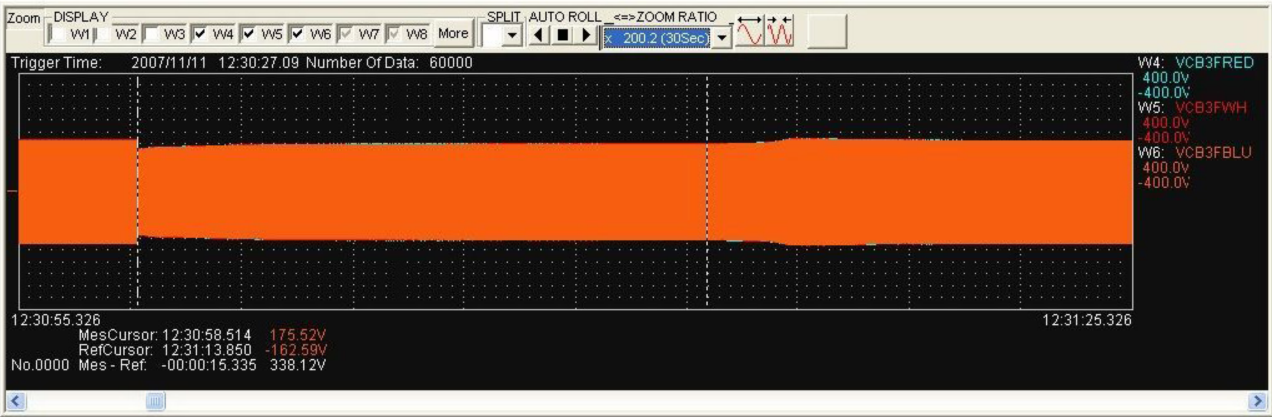
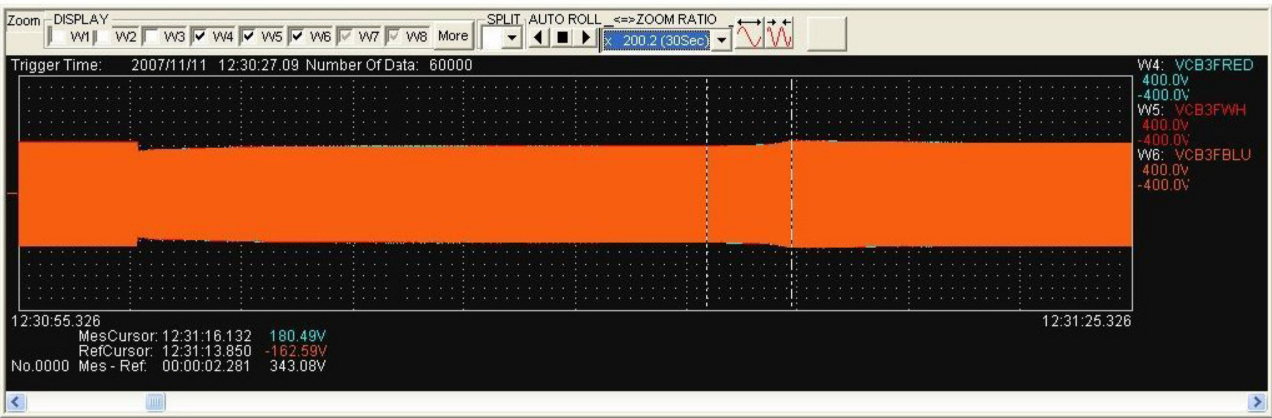


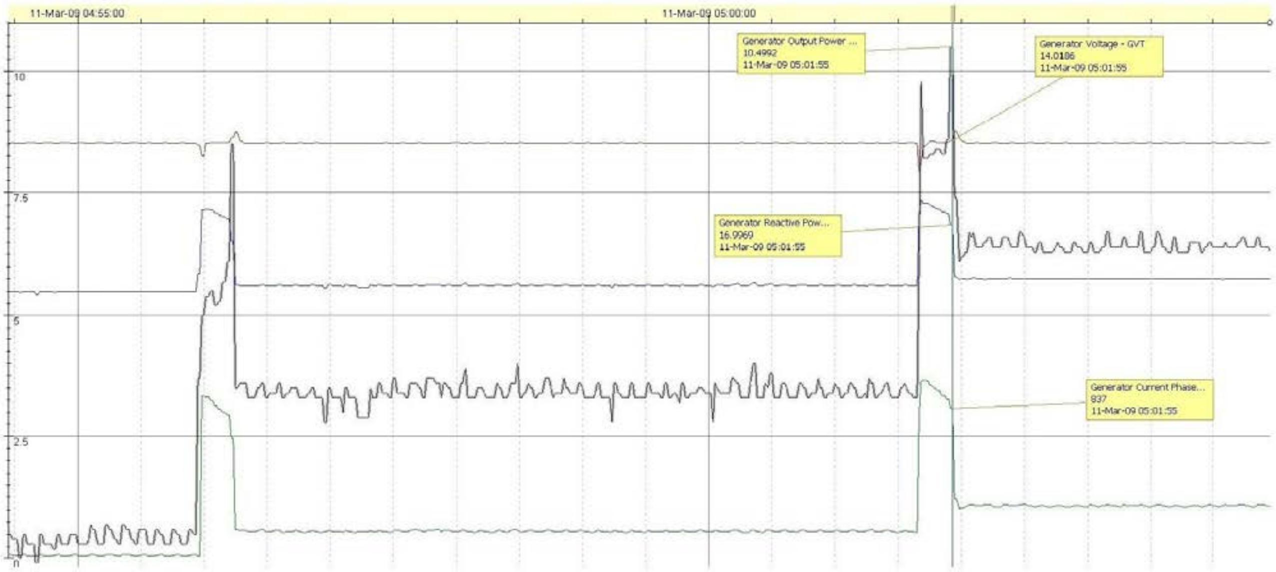
FIG. 27. Start time for first set of 2 HT system pumps.

Stop time for first set of 2 pumps 12:31:16.132



Total Time voltage to recover = 12:31:16.132 - 12:30:58.514 = 17.618 seconds

FIG. 28. Stop time for first set of 2 HT system pumps.



Legend

	Name	Start	End	Duration	Scale	Units	Min	Max	Avg
	Generator Output Power - GWT	11-Mar-09 04:54:26	11-Mar-09 05:04:26	00:10:00	0 - 11	MW	-0.2	10.4992	3.933629
	Generator Reactive Power - GVRT	11-Mar-09 04:54:26	11-Mar-09 05:04:26	00:10:00	-70 - 70	MVAR	-0.800625	23.8	2.689404
	Generator Voltage - GVT	11-Mar-09 04:54:26	11-Mar-09 05:04:26	00:10:00	0 - 18	KV	12.9589	14.3196	13.935792
	Generator Current Phase B - GAT	11-Mar-09 04:54:26	11-Mar-09 05:04:26	00:10:00	0 - 3000	AMPS	9	999.938	206.820411

FIG 29. Voltage trend at APS CTU2 generator during P941 — 2-0 heat transport test.

SUMMARY:

The Auxiliary Power System (APS) was tested on 11 March 2009 to confirm its ability to start the PHT pump motors as per P-D 50000-00003.

The PHT Pump motors 4-33120-PM5 and 4-33120-PM6 were started from the Auxiliary Power System (APS) simultaneously. Similarly, the PHT pump motors 4-33120-PM9 and 4-33210-PM13 were also started from the APS.

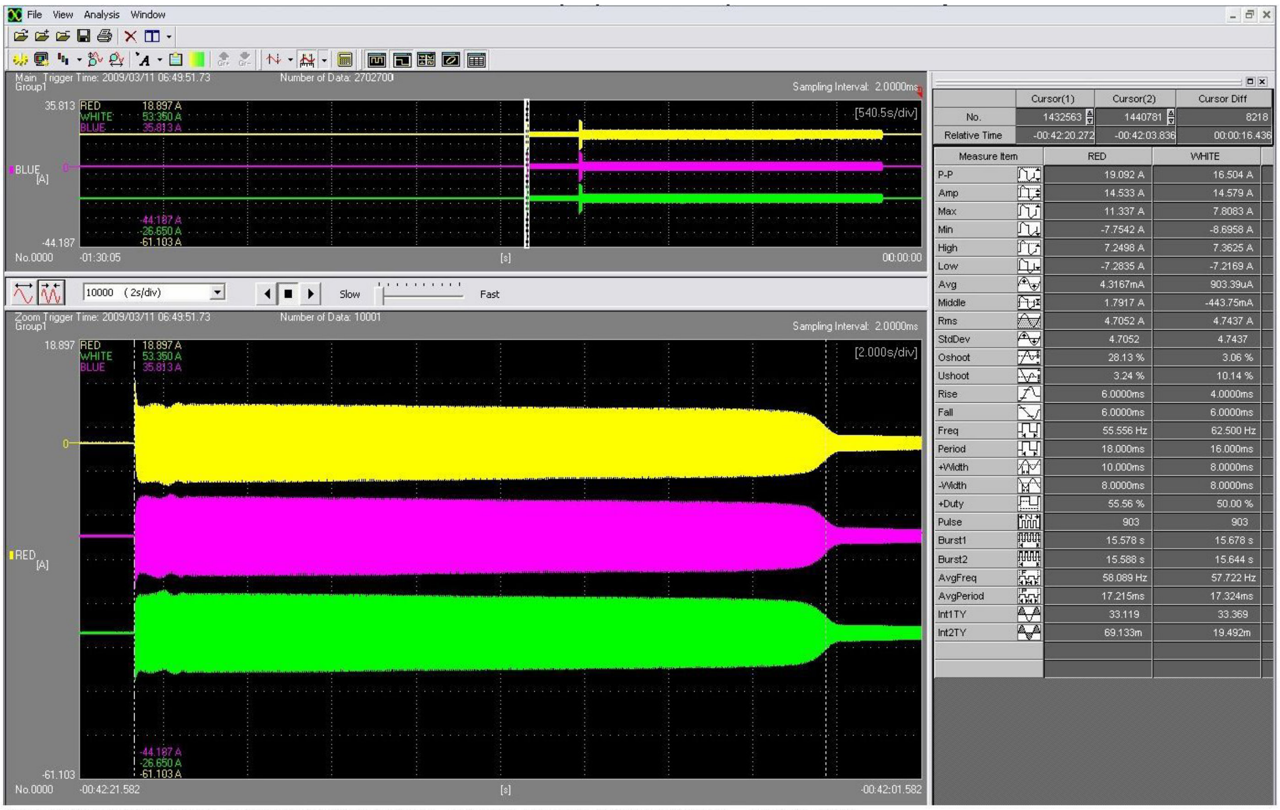
The start up on both occasions was successful and as expected with no APS malfunction.

The Inrush Current and the duration were measured at CB1XE and CB21A. The four printouts are attached. The results are summarized below.

PUMP	Recorded at CB1XE		Recorded at CB21A	
	Inrush Current Amps	Inrush Duration Seconds	Inrush Current Amps	Inrush Duration Seconds
4-33120-PM5 and 4-33120-PM6	2823	16.436	2327	16.415
4-33120-PM9 and 4-33120-PM13	3115	16.976	2529	17.085

The results are acceptable to Design.

FIG. 30. Test summary report.



Stop Time for inrush current for first set of 2 PHT pumps (PM5&PM6) – 42:03.836
Total time for inrush current – 42:20.272-42:03.836 = 16.436 sec
Total Motor Starting Current of first 2 pumps = 4.7052A (see table above) x 600 (CT Ratio) = 2823 A

FIG. 31. Current for pumps PM5 and PM6 measured at CB1XE.

Appendix VIII

CONDUCTING AVAILABLE FOR SERVICE MEETINGS

The purpose of an AFS meeting is to provide quality oversight for management to ensure the design, installation and commissioning activities have been properly completed prior to the release by commissioning of the modification or system to the operating organization. This appendix describes typical AFS meeting requirements.

Every permanent plant modification is typically subject to an AFS meeting. For modifications that are to be performed on multiple units over an extended period of time, an AFS meeting is conducted upon the completion of the modification on a given unit. Where modifications on a given unit are installed in stages (e.g. for each of three pumps installed in parallel) and there is a need to turn over the equipment covered by that stage to operations, a so-called ‘partial AFS’ may be completed to confirm that reactor operation is not adversely impacted by the completed stage. Note that a partial AFS is somewhat different than the construction contract concept of ‘substantial completion’ of a project, which is the point where the owner can make use of the building or facility and ordinarily only minor work remains (e.g. punch list items). A partial AFS can be for a relatively small portion of a project (for example one instrument out of many), but does specify that the equipment covered by the scope of the partial AFS has been formally commissioned and transferred to the control of operations.

Certain low impact, minor modifications may be exempted from a formal process per the operating organization’s management system.

The individual responsible for overall implementation of the work arranges for the meeting and invites representatives from key organizations to attend. These may include representatives from:

— Construction;
— Commissioning;
— Operations;
— Maintenance;
— Design;
— Reactor safety (if there is impact on nuclear safety);
— Security (if there is impact on security systems);
— System engineering;
— Component engineering;
— Chemistry group (if applicable);
— Environmental group (if applicable);
— Industrial safety group (if applicable);
— Radiation safety group (if applicable);
— Regulatory bodies (as necessary or as a courtesy).

If knowledgeable persons with authority to sign off for the respective parties do not attend the meeting, the meeting is normally cancelled and rescheduled to a time when all parties can attend.

A senior engineering manager who has not been directly involved with the modification is typically appointed AFS meeting chairperson. The chairperson becomes familiar with the modification before the meeting (reviewing documentation and attending a field walkdown), ensures that the meeting has a quorum, confirms that a formal AFS meeting package has been prepared, runs the meeting and appropriately challenges AFS attendees and involved parties as to the suitability of declaring the related modification or system in service. A separate person with a ‘black hat’ role can also be assigned to perform a similar challenge function. During the meeting, the AFS declaration is reviewed (see sample in Appendix V), along with key commissioning results.

Specific duties of the chairperson during the meeting can include the following:

— Questioning to understand alignment of installation and commissioning with design requirements.
— Clearly establishing any outstanding actions and ensuring they are identified with applicable plant milestones (e.g. plant startup hold points). Directing remedial action if the modification is not at an acceptable point to proceed.

- Ensuring that all design products are complete, all documentation is submitted for updating and required reviews are complete.
- Asking the senior operations representative at the meeting if he or she is satisfied that training, procedures and outstanding actions are acceptable for operation.
- Asking the senior maintenance representative at the meeting if he or she is satisfied that procedures, installation and training are such that the modification can be properly maintained.
- Asking the senior nuclear safety representative at the meeting if he or she is satisfied that the regulatory requirements for the modification have been met and if any requirements imposed on plant evolution by the modification have been clearly identified/communicated.
- Confirming that all affected document list items (including field changes) have been updated or sent for updating (per management system requirements), and that electronic databases of modification and equipment status have been updated.
- Ensuring that any outstanding items, deviations from the design, and installation and commissioning specifics have been appropriately resolved and tracked by the responsible parties.
- Ensuring that all outstanding actions are tracked with reasonable completion dates (e.g. typically no more than six months beyond the AFS date).

Where the modification cannot be fully commissioned (i.e. has non-commissionable attributes as described in Section 4.6), enhanced scrutiny over how these attributes have been proven should be included in the meeting.

At the conclusion of the meeting, the responsible individuals sign off on the AFS declaration form and the modification is declared available for service by the appropriate plant engineering and operating authorities.

ABBREVIATIONS

AFS	available for service
AIA	authorized inspection agency
ANO	authorized nuclear operator
APS	auxiliary power system
BECx	building envelope commissioning
CANDU	Canada deuterium–uranium
CMOD	commercial modification
CNE	Chief Nuclear Engineer
CSA	Canadian Standards Association
CTU	combustion turbine unit
DCEM	Direction Commissioning Engineering Manager
DCN	design change notice
DCP	design change package
DTL	Design Team Leader
EPC	engineering, procurement and construction (contract type)
EPRI	Electric Power Research Institute
FAT	factory acceptance test
FTL(I)	Field Team Leader (installation phase)
HPECI	high pressure emergency coolant injection
HSI	human–system interface
HT	heat transport
HVAC	heating, ventilation and air conditioning
I&C	instrumentation and control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITP	inspection and test plan
LOBES	loss of bulk electrical system
MCR	main control room
MTL	Modification Team Leader
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
OSART	Operational Safety Review Team
PHWR	pressurized heavy water reactor

PMOD	permanent modification
PNSC	plant nuclear safety committee
SAT	site acceptance test
SCEM	Shift Commissioning Engineering Manager
SES	site electrical system
SIT	site integration test
SSC	system, structure or component
TAB	turbine auxiliary bay

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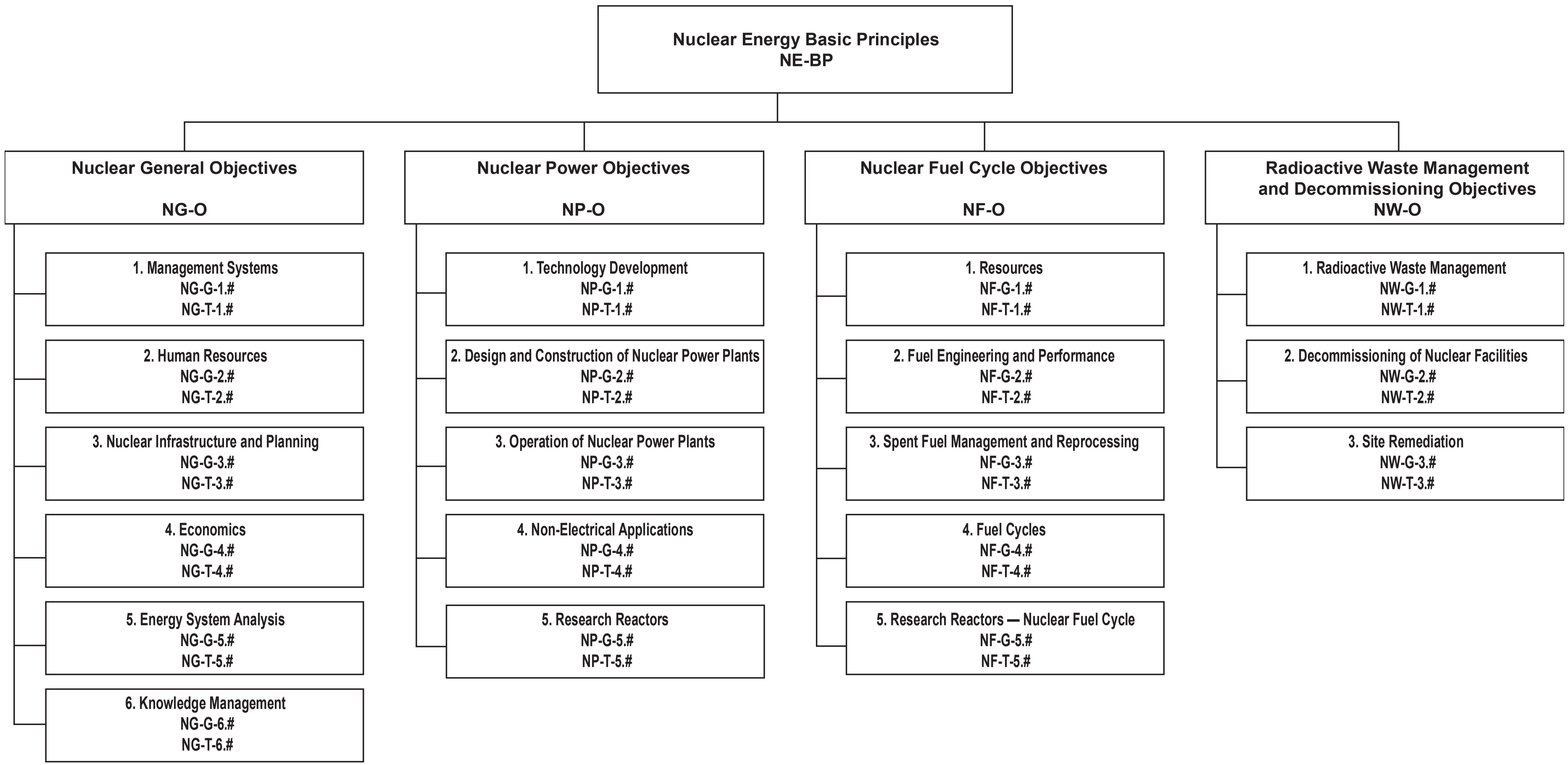

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BP: Basic Principles
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