IAEA Nuclear Energy Series

No. NR-G-5.3

Basic Principles

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Project Management in Construction of Research Reactors

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IAEA NUCLEAR ENERGY SERIES PUBLICATIONS

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PROJECT MANAGEMENT IN CONSTRUCTION OF RESEARCH REACTORS

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

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FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology. While the guidance provided in IAEA Nuclear Energy Series publications does not constitute Member States' consensus, it has undergone internal peer review and been made available to Member States for comment prior to publication.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

The interest of IAEA Member States in developing research reactor projects has grown significantly in recent years, and several Member States are currently in different stages of new research reactor projects for the development of their nuclear science and technology programmes. The significant construction, operating and decommissioning costs of research reactors mean that the investment body (often the government of a Member State) will require efficient processes to be used during the major parts spanning the lifetime of the facility so that costs can be optimized. Employing good practice project management during construction will support the delivery of a facility that is ready for commissioning and operation. Project management is concerned with the definition, coordination and control of large undertakings and has within its remit the objectives of scope, technical quality, schedule and costs. Improved direction, control and expediting of the construction of research reactor projects by competent project management provides opportunities to reduce costs through efficient conduct of work, higher workforce productivity, intelligent choices on procurement, and the precise scheduling of testing and installation of systems, structures and components, all of which are intended to deliver a safe facility and reduce the financial burden during construction.

This publication draws on proven practices in a number of Member States to provide guidance on project management during the construction of a research reactor facility, from the preparatory phase to turnover for commissioning. It also includes experience gained and lessons learned from project management for significant modifications of research reactors. The publication is intended to support project managers and their staff in better managing research reactor construction and modification projects and thereby contribute to establishing research reactors in Member States as viable and safe infrastructure for nuclear science and technology.

The IAEA wishes to thank all contributors to this publication, in particular G. Storr (Australia), who compiled the draft versions of the text through two consultancy meetings. The IAEA officers responsible for this publication were Y. Cho and A. Sitnikov of the Division of Nuclear Fuel Cycle and Waste Technology, A. Shokr of the Division of Nuclear Installation Safety and D. Ridikas of the Division of Physical and Chemical Sciences.

CONTENTS

1. INTRODUCTION

This publication addresses project management for the construction of research reactors and gives guidance to Member States on the best practices that will assist in the physical realization of a research reactor, which in many cases will be an important piece of national infrastructure.

It is emphasized in various IAEA publications that a research reactor project is a major undertaking requiring careful planning, preparation and investment in time, money and human resources. In particular, there are publications that detail the specific milestones required for a research reactor project, from initial concept through to preparation for operation [1], that discuss preparing a strategic plan for research reactors [2] and that address the diversity and complexity of research reactor utilization [3, 4].

The period during which a research reactor is constructed is when the major capital investment is made, and the design of the reactor is transformed from a concept and plans into a tangible physical asset, which at the end of construction needs to be ready for fuel loading and first criticality. While the construction period usually does not involve the use of nuclear material or the operation of the reactor, it is still necessary to attend to nuclear safety and nuclear security requirements, as this is the period where the research reactor, the operating organization and all the stakeholders of the research reactor are preparing for its future operation and utilization, which will typically last for decades.

The guidance contained within this publication is based on proven practices in several Member States. It covers project management from the preparatory phase of construction to turnover of the reactor for fuel loading, all commissioning activities associated with nuclear fuel and future operation. With this guidance, project managers and their staff should be able to better manage research reactor construction and major modification projects and thus contribute to establishing research reactors in Member States as viable and safe infrastructure. This will assist with realizing the benefits of peaceful nuclear science and technology worldwide.

1.1. BACKGROUND

Research reactors come in a broad range of types and sizes and may be used for many different applications. Many research reactors employ complex systems, and, as with all types of nuclear installations, safety and quality requirements should be high over the life cycle of the reactor, through design, construction, operations, modifications and decommissioning [5]. The IAEA Research Reactor Database [6] classifies research reactors by power as follows:

(a) Low power reactors, ≤1 kW;
(b) Medium power reactors, 1 kW–1 MW;
(c) High power reactors, >1 MW.

Generally, the thermal capacity of the reactor is representative of reactor characteristics such as the density of neutrons generated in the reactor core, the possibilities for the range of experiments that could be undertaken, the physical dimensions, the equipment structure, and the broad level of financial and material resources required for construction.

The significant construction, commissioning, operation and decommissioning costs of research reactors mean that the funder, which is very often the government of a Member State, will require efficient processes to be used during the lifetime of the facility so that costs are optimized. Employing good practice project management throughout the research reactor project will allow for the delivery of a functional and safe facility. During construction, good project management practices and good leadership by a capable and experienced project manager will enable time, costs and quality to be well managed.

The IAEA publication applicable to the construction of nuclear installations [7] provides recommendations and guidance on the basis of international good practices, aimed at enabling construction to be of high quality, consistent with the design requirements and as agreed by the regulatory body in issuing the authorization for construction. In addition, an IAEA guide for the construction of nuclear power plants [8] may be useful reading for research reactor operators and regulators.

Project management is a discipline that is concerned with the definition and development of designs plus the coordination and control of fabrication and construction work to achieve specific goals. Projects exist for small and large undertakings and have within their remit objectives for scope, time, cost and technical quality. Typically, research reactor projects are complex undertakings that require competent project management techniques, efficient work practices, an appropriately trained and productive workforce, intelligent procurement choices and optimized scheduling for construction, testing and commissioning of structures, systems and components (SSCs) to achieve the project goals.

According to the IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [9], the first principle for safety is that “**The prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.**”

This means that the operating organization is responsible for safety. It is explained that safety in this context pertains to nuclear and radiation safety. Since construction will often not require nuclear and radiation safety to be implemented directly, the question arises as to which organization has responsibility for safety during construction, as many operating organizations will choose an external vendor or vendors to undertake the construction of the research reactor. In the IAEA's publication on specific safety requirements for research reactors, IAEA Safety Standards Series No. SSR-3, Safety of Research Reactors [5], Requirement 2 states that:

> "**The operating organization for a research reactor facility shall have the prime responsibility for the safety of the research reactor over its lifetime, from the beginning of the project for site evaluation, design, construction, commissioning, operation, including utilization and modification, and decommissioning, until its release from regulatory control.**"

Therefore, safety during the construction period resides with the operating organization. In practice, during the construction period, the operating organization may delegate control to the contractor and construction company, but the prime responsibility for safety still resides with the operating organization.

In general, all activities across the life cycle of a research reactor should be managed using an integrated management system. During the construction period the operating organization should organize the development and implementation of a quality assurance programme for construction of the research reactor and should monitor the quality assurance of the activities of all organizations performing work on and providing services for the construction.

Regulatory bodies have a very important role to play during the construction period, as their responsibilities for review of the design, the issuing of licences for construction, commissioning and operation, and physical and documentation reviews, span the construction period.

1.2. OBJECTIVE

The objective of this publication is to provide guidance on project management for the construction of a research reactor and for major modification projects at existing research reactors. Therefore, the publication is applicable for Member States procuring their first research reactor, for those replacing an existing facility, for those procuring a new and additional facility and for those undertaking major modifications at an existing facility. The guidance provided is primarily intended for operating organizations and regulators, but it is recognized that the guidance should also be useful for vendor organizations. It is further recognized that details of the requirements for research reactor projects may vary among Member States due to differences in laws, government policies, regulations, funding requirements, stakeholders, utilization of the reactor and experience with operating nuclear facilities.

1.3. SCOPE

This publication provides guidance on project management for a research reactor project from the start of preparations for construction, through construction itself, which is defined as commencing at first concrete pour, and through the completion of construction, which includes integrated systems testing.

The publication includes consideration of both ‘hard’ (e.g. engineering, equipment, facilities) and ‘soft’ (e.g. legislative, regulatory, training) items and project management issues involved in building the infrastructure and systems necessary for a safe and operational research reactor and associated facilities.

The concepts and definitions used in the IAEA publication on Specific Considerations and Milestones for a Research Reactor Project (IAEA Nuclear Energy Series No. NP-T-5.1) [1] are followed in this publication. Three major infrastructure phases with associated milestones for a complete research reactor project are defined in the Milestones publication, and these are shown in Table 1.

TABLE 1. INFRASTRUCTURE DEVELOPMENT PHASES AND MILESTONES
(adapted from Ref. [1])

Phase	Description	Milestone
(1) Pre-project	Justification of the research reactor and considerations before a decision to launch a research reactor project is taken	Ready to make a knowledgeable commitment to a research reactor project
(2) Project formulation	Preparatory work for the construction of a research reactor after a policy decision has been taken	Ready to invite bids for the research reactor
(3) Implementation	Activities to design and construct a research reactor	Ready to commission and operate the research reactor

This publication deals with the activities that are undertaken during Phase 3 — implementation. The Phase 3 milestone of 'ready to commission and operate the research reactor' implies that preparation for commissioning should be undertaken during the construction period. In practice it is noted that the IAEA defines stages for the commissioning of a research reactor [10] and that the first stage, called Stage A commissioning, entails integrated systems testing of the facility, which is the verification that systems perform as intended. This verification is required prior to the loading of nuclear fuel. The transition between construction and commissioning will involve significant changeovers in terms of systems, operations and responsibilities. Therefore, the planning for these changeovers and the communication between the responsible parties and organizations are critical activities during the construction period. The transition between construction and commissioning should be consistent with the responsibilities and activities agreed with the regulator. Additionally, in practical terms there may be some construction activities and tasks that need to be completed after fuel loading and perhaps extending into the early operation phase if, for example, construction defects are identified and need to be rectified.

Figure 1 shows a global process diagram that displays the relationships between the phases of a research reactor project and the scope of issues covered in this publication.

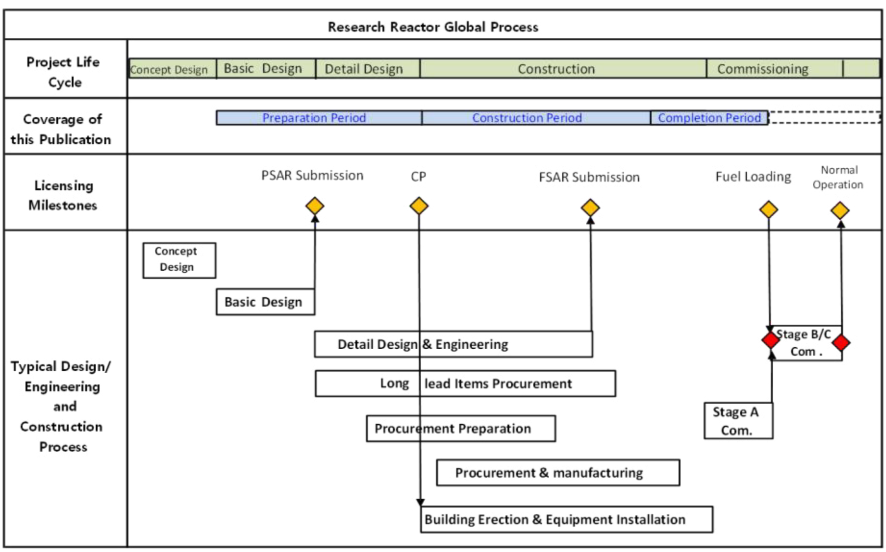

FIG. 1. The global process for a research reactor project, showing the project life cycle, the coverage of this publication, licensing milestones and major engineering processes.

The information presented in this publication is based on the experience and good practices of countries with research reactors and is not intended to impose standards on those contemplating a new research reactor.

1.4. STRUCTURE

The implementation phase (Phase 3) of a research reactor project can be divided into three sequential time periods: the preparation period, the construction period and the completion period. The publication is organized following this structure.

Depending on the complexity of the design and the type of research reactor being constructed, the implementation phase may take anything from one year to several years from commencement of the phase until completion. There have been cases where this period is even longer, but these have usually involved delays caused by funding or technical problems.

Section 2 addresses the construction preparation period, including the interaction with the facility design, organization of the project team and management of the early stages of construction.

Section 3 addresses the construction period, where the major part of the construction work for the facility is undertaken.

Section 4 addresses the construction completion period, where construction is completed, individual and integrated system tests are performed, and the facility is prepared for fuel loading and commissioning stages B and C. In Section 4 the links to commissioning are explored, including the important issues of transfer of responsibility and turnovers.

This report also provides case studies of individual Member States experiences in the management of specific research reactor construction projects.

2. CONSTRUCTION PREPARATION PERIOD

The construction preparation period commences either at or close to the time when Milestone 2 (‘ready to invite bids for the research reactor’) is achieved and concludes when the first concrete pour occurs on the basis of the overall project schedule. The major activities to be performed during the construction preparation period will comprise all the design, analysis and licensing work for application of the construction permit and achieving these activities within the predefined project schedule. In addition, some significant construction preparation work may be undertaken, such as site clearing, excavation, road building and erection of temporary buildings for construction.

The construction preparation period encompasses many important elements of the project being initiated and prepared, and overall it is a time when planning and preparation are vital; if they are done well, they will contribute to the success of the project.

2.1. INFRASTRUCTURE ISSUES

Reference [1] defines 19 infrastructure issues that require consideration during a research reactor project, and these issues are listed in Table 2. A few items are linked to national or international commitments the Member State should establish in advance and maintain during the execution of a research reactor project. This publication deals with detailed activities and tasks that either underpin, interact with or support the 19 infrastructure issues.

2.2. MAJOR CONSIDERATIONS

Major issues for the construction preparation period are considered below, and it is noted that the first major consideration is related to the management of the project and the selection and responsibilities of the project manager. While the details of many of the responsibilities, activities and tasks of the project manager are given for the construction preparation period, in practice many of these will be required throughout all three construction periods.

TABLE 2. INFRASTRUCTURE ISSUES FOR A RESEARCH REACTOR PROJECT *(adapted from Ref. [1])*

National position	Stakeholder involvement
Nuclear safety	Site survey, selection and evaluation
Management	Environmental protection
Funding and financing	Emergency planning
Legislative framework	Nuclear security
Safeguards	Nuclear fuel management
Regulatory framework	Radioactive waste
Radiation protection	Industrial involvement
Research reactor utilization	Procurement
Human resources development	

2.2.1. Project manager

The management of a research reactor project is a demanding task, and highly competent management is one of the key components for project success. The early appointment of a skilled and experienced project manager is advisable, and ideally this should occur prior to Phase 3, or at the latest coincide with the commencement of Phase 3. It may not be necessary for the project manager to have a nuclear background, provided that sufficient and relevant nuclear skills are possessed by members of the project team or by other people who may be seconded to the project team and can provide advice as and when required.

The project manager should define the project team, its structure and working arrangements, including the detailed roles and responsibilities of the project team members. The project manager should establish the project team using an approved and rigorous recruitment process to ensure that it possesses the required skills and capabilities. Some members of the project team may continue or be replaced during subsequent stages of the project, based on the changing needs of the project as it progresses. Because of the complexity of these types of projects, which progress through stages, it is important that a degree of flexibility be applied to project team membership. Project team members should all be made aware that projects are, by definition, of finite length, and effective execution of the project requires some flexibility in response to changing circumstances.

The responsibilities of the project manager's role are multiple, and at the strategic level this may be summarized as leading the project so that the project is delivered on time, on budget, and consistent with the project scope and the necessary level of quality. As a first step, this means documenting and articulating the project mission, aims and goals. At an operational level, this translates to executing the work, controlling the project and supporting others so that the project succeeds.

During Phase 3 of the project, the project manager will be required to oversee execution of the construction work, be the primary person responsible for controlling the project and provide the support necessary to complete construction. The major activities of the position during the construction preparation period and associated detailed tasks that are linked to the major activities are described below.

2.2.1.1. Oversee work execution

The project manager should:

(a) Be responsible for preparing the project execution plan and integrating relevant activities with the operating organization, and define the project work activities and tasks, including those that are needed to satisfy the various regulatory requirements and quality assurance requirements. If the project work activities and tasks have been completely or partially defined previously, for example by the operating organization or the funding body, then the project manager would be expected to review and, if necessary, refine the project work activities and tasks.

(b) Produce a detailed project plan addressing the work breakdown structure (WBS) of the project, with estimates of resources, costs, schedule, deliverables, milestones, hold points, interdependences and risks.

(c) Outline alternative approaches to the project, taking consideration of risks that may eventuate to affect it.

(d) Communicate the project plan to the regulatory body and government once the plan has been reviewed and approved by the operating organization.

(e) Ensure there is a formal communication channel between the project and regulatory body.

(f) Define the sequence of activities and tasks and commence co-ordination of the project activities at the level appropriate for the complexity of the project.

(g) Ensure that the available funds and resources match the project plan.

(h) Negotiate and finalize contracts required for execution of construction activities and tasks.

(i) Recruit technical personnel for the construction project and provide opportunities for formal training in order to create a culture that contains the levels of safety, security and quality that are necessary for a nuclear organization.

(j) Provide the necessary staff and the appropriate delegation authorities for those staff for the project activities and tasks to be carried out effectively.

(k) Develop bid evaluation criteria, contracting strategy and supporting financing strategy, early in the project.

(l) Prepare for nuclear fuel and fuel cycle services supply.

(m) Interface with the operating organization to ensure interdependences and risks are identified and understood, planned for and mitigated. Examples of interdependences include planning for future spent fuel and radioactive waste management issues from the operating reactor facility.

(n) Plan technology transfer arrangements.

(o) Plan for recruitment and training of future operating staff.

(p) Identify and ensure compliance with regulatory (including licensing scheme) and safeguards requirements.

(q) Ensure that the construction site is prepared for construction activities.

2.2.1.2. Project control

The project manager should:

(a) Deal directly with, or effectively delegate to others, problems that hinder the progress of the project or threaten its quality;
(b) Conduct regular meetings with project staff and project partners to monitor progress, take necessary corrective actions and communicate essential project information;
(c) Control expenses and project performance against the contracts, budget and schedule, and obtain authorization from the operating organization and funding body for major project changes;
(d) Monitor the technical progress of the project in the issuance of analysis reports, specifications and drawings by ensuring high quality and compliance with requirements;
(e) Appoint a risk committee to consider technical, financial, political and environmental risks;
(f) Report to the operating organization and, if necessary, the funding body on project progress at agreed frequencies.

2.2.1.3. Other supporting functions

The project manager should organize the provision of necessary administrative services to support the project, including the following:

(a) Finance and accounting;
(b) IT and computer systems;
(c) Legal and insurance;
(d) Engineering services that understand and support compliance with the codes and standards necessary to ensure that the project is delivered to the required regulatory and quality levels;
(e) Workplace health and safety systems necessary for construction.

2.2.2. Contract for supply of the reactor

2.2.2.1. Type and approach

The contract for supply of the research reactor will usually be one of three types: turnkey, split package or multiple package. The decision on the type of contract may be made by the government of the Member State, the operating organization, the project manager, or a combination of the three. The project manager will be responsible for managing the supply and outcomes from the type of contract chosen:

(a) In a turnkey contract, a single contractor or consortium of contractors takes overall responsibility for completing all parts and all phases of the project design and construction.
(b) In a split package contract, the overall responsibility for design and construction for the project is divided among a relatively small number of contractors. Each contractor is separately in charge of a large section of the work.
(c) In a multiple package contract, the operating organization, usually with the assistance of consultants, assumes overall responsibility for managing the design and construction project. A large number of contracts are issued to various contractors who carry out parts of the project.

The main factors to be considered when deciding on the contractual approach include:

(a) The Member State's national needs, including its nuclear and research policies and programmes.
(b) The Member State's domestic participation policy and plans for the development of local engineering and industrial capabilities.
(c) The operating organization's experience in procuring, constructing and operating research reactors.
(d) The availability of qualified project management personnel and coordinating and engineering personnel.
(e) Existing engineering and industrial infrastructure.
(f) Capability to build supporting infrastructure, including in respect of:
    (i) Regulatory and licensing bodies;
    (ii) Nuclear fuel procurement, transport, and management;
    (iii) Future reactor operation and maintenance;
    (iv) Radioactive waste management and storage;
    (v) Decommissioning.
(g) Availability of technical assistance from the current or future operating organization.
(h) Ability to plan, prepare and maintain a bid evaluation schedule.
(i) Ability to assess potential suppliers and, if warranted, prequalify them with regard to their engineering and construction experience and management and contract practices.
(j) Experience of the reactor owner with large scale projects.
(k) Reactor design criteria and engineering features.

(l) Standardization and the degree of demonstrable technology for the proposed reactor and ancillary facilities.

2.2.2.2. Owner's scope of supply

For all types of contract, there is an owner's scope of supply, which defines the activities and tasks that will be performed by the owner. The owner's scope of supply can vary greatly, depending on the size, experience and capabilities of the owner's organization.

The project manager may be required to vary or modify the scope of supply during subsequent stages of the project, and if this occurs, the owner may need to give approval for variations of high complexity or cost or that affect safety. In some cases, the regulator may also be involved in the review and approval process.

Decisions that affect the safe and efficient operation of the research reactor will remain the responsibility of the operating organization.

2.2.2.3. Methods of bidding

The tender process will specify the bidding method to be used. Typical bidding methods include the following:

(a) Open bidding: this occurs when the tender is advertised, and the process is theoretically open to all bidders. The characteristics of this method include openness, equal opportunity, terms and conditions specified to all, and relatively long periods for the tender and bidding.
(b) Tender by specified bidders: this occurs when the tender is by invitation and the process is open to selected potential suppliers. The characteristics of this method include easier bidding procedure management and relatively low risk of disputes in implementation.
(c) Negotiated contract: this occurs when there is no competition and the supplier is selected without tender. The characteristics of this method include a closed process, confidential financing arrangements, confidential terms and conditions, and a relatively short period for implementing the supply contract.

Irrespective of the contracting method, the project manager, typically in consultation with the operating organization and funding agency, may be required to make decisions on financial and legal terms for the bid; for example, the institution of a bid bond for each bid and the conditions for possible time extensions and cancellations.

2.2.2.4. Bid selection methods

Various methods can be used to select the best bid, with the method chosen being influenced by factors such as government procurement policies, the maturity of the operating organization and the method of bidding to be applied. The bid selection methods given below, while not exhaustive, cover the range of bid selection methods for a broad range of supply of a new research reactor:

(a) Quality and cost based selection;
(b) Quality based selection;
(c) Selection under a fixed budget;
(d) Least cost selection;
(e) Single source selection.

2.2.2.5. Contract structures

Contracts are legal mechanisms that allow separate entities (organizations, companies, individuals) to transact by determining and defining the rights and obligations of each entity. The structures that may be used in research reactor projects include the following:

(a) Bilateral contract;
(b) String contract;
(c) Parallel contract;
(d) Consortium contract.

2.2.2.6. Pricing structures and payments arrangement

The type of contract will have an influence on the financial model used for the project, with the more complex types of contracts having risk and reward components linked to the supply items specified in the project. Some contracts will include performance clauses where incentive payments (or penalties) are made contingent on certain performance levels being achieved. For a research reactor, this may be related to neutron flux levels and energy spectra measured in specified facilities. Such performance payments will be linked to the successful operation of the reactor and measurements made after the first criticality is achieved.

The total contract price for the reactor includes the direct project cost, including construction site expenses plus the markup imposed by the contractors for overheads and profit. More detailed and separate pricing may be applied to certain structures or components that are supplied. These may be dependent on the design and the type of contract. Typical pricing structures may include the following:

(a) Fixed price: the price is fixed in accordance with the economic conditions prevailing when the contract is signed. It is fixed and does not vary, irrespective of supply issues that occur during the project. Payments made for work progress, within the scope of supply of services, could be subjected to a pre-agreed adjustment. A ceiling for such escalation has to be indicated within the contract.
(b) Reimbursement: the contract specifies reimbursement of project costs plus additional fees, as specified within the contract.

2.3. EVALUATING BIDS AND CONTRACT NEGOTIATION

The contract type, the technical complexity of the project, the maturity of the operating organization or owner, and the contract and pricing structures will all have an influence on the process chosen for evaluating the bids and the negotiation of the contract. This section gives an example of how to structure an evaluation of the bids and provides issues that are relevant and should be considered when negotiating a contract for supply of a research reactor facility.

The operating organization or owner, in consultation with the project manager, should organize the evaluation so that there is clarity about three major aspects of the bids: technical, legal and commercial. Having personnel who are skilled in these major areas will be crucial to the evaluation process, and having an evaluation team who can integrate the evaluation areas is also crucial.

In the following discussion, it is assumed that there is more than one bidder, that the proposals submitted by the bidding organizations have followed the advertised tender process and that the process requires a bid that contains separate technical and financial proposals. First inspection of the proposals may reveal that there are deficiencies in the information provided by some vendors. If there are deficiencies, be they technical, legal or commercial, a list of the missing categories of information should be prepared and communicated to the respective bidding organizations. Prior to the bid submission closing dates, clarification meetings may need to be held between a bidding organization and the operating organization or owner to clarify the issues. The intent is to ensure that all bids that are accepted for detailed evaluation meet the established tender criteria and constitute compliant bids.

2.3.1. Bid evaluation

The technical evaluation can be a demanding activity requiring in depth analysis from the evaluating team. It may go as far as performing independent calculations with the aim of verifying performance claims made in the submitted bids. The technical evaluation may rely on expertise from an existing operating organization or from independent contractors, should the operating organization or owner be a new entrant into the research reactor field.

The technical evaluation should comprise the review and investigation of all technical aspects of the supply. If the proposal for tender documents is sufficiently detailed, the categories and elements to be evaluated can follow the tender specifications. As a minimum, the following categories should be evaluated:

(a) Civil works — demolishing, excavations, all buildings and structures, balance of plant.
(b) Electromechanical works — electrical supply and distribution, alternative power supplies, mechanical equipment and works.
(c) Instrumentation and control systems — reactor, non-reactor.
(d) Reactor core — neutronics, thermal hydraulics, performance.
(e) Nuclear fuel — designs, manufacturer, raw material supply, transportation, security.
(f) Engineered safety features — reactor protection systems, shutdown systems, cooling systems, confinement/containment systems, post-accident monitoring.
(g) Experimental facilities — type and usage, safety.
(h) Safety and licensing — codes, standards, regulations, radiological protection, environmental management, safety analysis.
(i) Waste management — radioactive and non-radioactive, air, water, solid streams.
(j) Quality assurance — codes and standards, levels and requirements, construction, commissioning and operation.
(k) Training — technology transfer and training for commissioning and operation.

The evaluation of these categories could be based on compliance with the specifications in the tender, assuming that they are sufficiently detailed. In addition, the following aspects should be considered:

(a) Design — is the design proven? If the design of the proposed reactor includes novelties, the design should have been proven and preferably licensed elsewhere. Are the SSCs easy to construct? Are the SSCs serviceable, accessible and maintainable once installed? Will the answers to these questions enhance or detract from licensing the facility?

(b) Function and performance — neutron flux levels in core and facilities; independence and diversity of safety systems; calculated radiation levels in operating and shutdown states.
(c) Bidder experience — performance of other research reactor facilities that the bidder has been responsible for supplying.
(d) Records of construction, operation and reliability and safety of reactors and other nuclear facilities.
(e) Project schedule — milestones, phases, float and interdependences.
(f) National participation, technology transfer and training programmes.
(g) Assurance for supply of spare parts for SSCs.
(h) Component qualification, compliance with licensing requirements.
(i) In-service inspection, personnel radiation exposure during operations and maintenance.
(j) Quality assurance (QA)/quality control practice during construction, audits, documentation requirements.
(k) Guarantees and warranties.
(l) Assurance of supply for future nuclear fuel needs; provision for fuel reprocessing and future storage of waste.

The commercial evaluation is based on the following:

(a) Costs:
  (i) Research reactor total capital investment costs;
  (ii) Nuclear fuel cycle costs;
  (iii) Operation and maintenance costs;
  (iv) Total price of the project including escalation.
(b) Commercial and contractual terms and conditions:
  (i) Economic parameters;
  (ii) Project time and schedule.
(c) Economic life of the facility — depreciation and decommissioning costs.
(d) Financing terms and conditions.

The combination of the results of the technical bid evaluation and the corresponding interfaces with the commercial evaluation and legal opinion on the validity of the bid, contract and potential for meeting regulatory conditions will determine if a bid is acceptable. Figure 2 gives an example in flow chart form of a bid evaluation process combined with a contract negotiation for a research reactor facility.

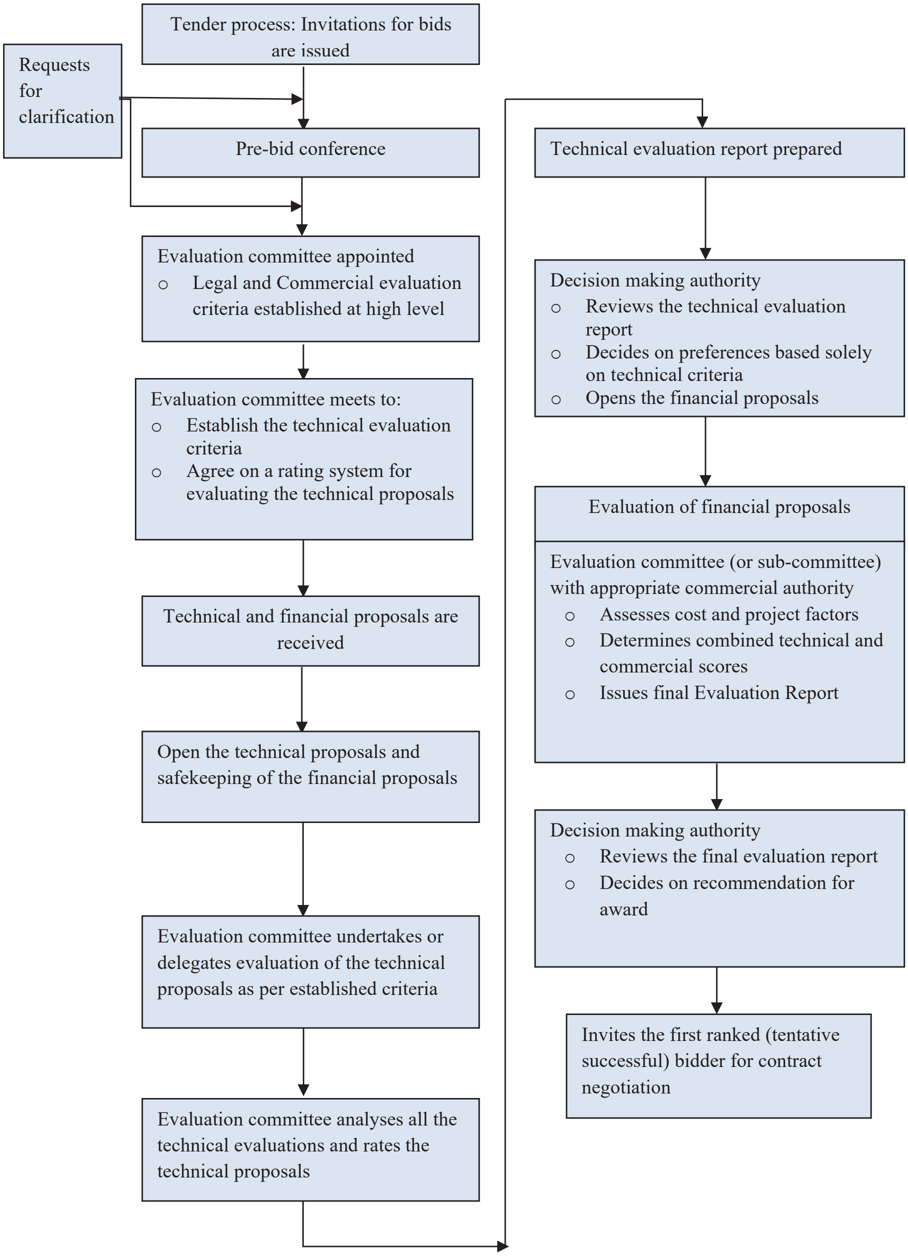

FIG. 2. Example of a process for evaluating bids for a research reactor facility.

2.3.2. Contract negotiation

The project manager may be delegated to undertake negotiations with the preferred bidder to finalize the terms of the project contract, or the operating organization or owner may decide to employ a professional negotiator. The advantage of project managers undertaking the task is that they should be intimately aware of the requirements for the project, and they have an opportunity to interact with the potential vendor at an early stage. The basis of the negotiations should be to achieve all the outcomes sought by the operating organization or owner, while establishing a relationship with the preferred bidder so that both organizations achieve their aims. Negotiation can be a difficult process and all people involved should try and maintain a professional approach and demeanour, be prepared to make concessions and be aware of the other parties' goals and needs. It is important to review and confirm with all parties as agreements are made during the negotiations. It should be recognized that the contract negotiation period may be stressful and short, and if a poor choice is made, this will present a risk for the whole project. Decisions on awarding the contract require high level approvals, and the operating organization should consider negotiating with more than one potential supplier if negotiations become difficult or protracted.

The personnel responsible for negotiation should have expertise in negotiation techniques and be excellent communicators, which includes being able to understand and analyse other parties' positions and opinions. Having a good understanding of the products and services to be delivered under the contract is important, and it is also important to understand the links between the technical and financial proposals to ensure that the final contract reflects the integrated outcomes required. Sensitivity to cultural, legal and work practice differences may be required if the negotiating parties have different countries of origin.

2.4. CONTRACT

Once the contract award is granted and the contract for supply of the research reactor facility is signed, both the principal (the operating organization or owner) and the vendor (the bidder that won the award) should understand and comply with their legal and fiduciary responsibilities as specified in the contract terms and conditions. Contracts may be interpreted differently in different countries, and it is therefore important that, in the early period of the contract, both parties spend time communicating diligently. A formal protocol for communication between the vendor and principal should be established early and adhered to throughout the contract. Because the contracting parties are likely to be from different countries, it is sensible to be aware of and make considerations for situational and logistical differences and issues, such as those concerning legal systems, regulatory laws and guidance, language, culture and customs, time and distance. Some of these may be amplified when there are disputes, or in the interpretation of contracts and technical documentation and conventions. The key to these situations centres on agreements to standardize and specificity in the contract.

2.4.1. Contract contents

The contents of a research reactor contract will be determined by a combination of the factors mentioned in Section 3.3 concerning bidding and contract negotiation. The principal and vendor should make plans to align the contract structure with the project work packages. This can assist first with the execution of the work and by making work package deliverables and payments consistent with the contract and second with preparation of the safety analysis report for the operational facility.

The tables below give an example of a generic contract structure. Table 3 shows the structure of the main part of a typical contract. Table 4 presents an example of the scope of general facility characteristics. The Table 5 provides an example of the scope of project management issues for the construction stages. Examples of work breakdown structure packages are listed in Table 6.

TABLE 3. CONTRACT — MAIN PART

Section	Comment
Formal agreement and legal instruments	Parties to the contract, legal basis and pertinent laws
Definitions	Specifies terminology and nomenclature
Contract conditions	Specifies the general conditions applicable to the contract, including the obligations of each party
Statement of work	Summary of the supply and scope of work
Detailed conditions of contract	May be specified in chapters or annexures associated with WBS packages (see below)

TABLE 4. GENERAL FACILITY CHARACTERISTICS

Section	Comment
Design	Design philosophy and requirements
Construction	Standards and expectations
Safety and licensing	Requirements for facility safety and licensing
Documentation	Requirements for documents, plans and drawings of the facility
Buildings and structures	Defines all buildings and structures in the supply
Waste management	Expectations on managing all waste during and after construction
Balance of plant	Any elements of the supply not specified already may be listed here
General finishes	Quality and standard on finished products

TABLE 5. PROGECT MANAGEMENT DURING CONSTRUCTION

Project management plan and schedule
Safety and licensing
Project quality assurance
Risk management
Environmental management and compliance
List of standards, codes and practices
Construction, inspection and test plan
Local industry contribution
Services schedule
Technology transfer plan
Consolidated list of tools and equipment
Commissioning plan

TABLE 6. WORK BREAKDOWN STRUCTURE PACKAGES

Reactor
Reactor cooling systems
Reactor protection system and emergency management
Engineered safety features
Instrumentation and control
Electric power
Nuclear fuel provision and/or handling and storage
Experimental facilities
Operational limits and conditions
Waste management
Reactor facility operations
Security and safeguards
Safety assessment
Reactor auxiliary systems
Fire protection
Facility quality management system
Training of operation and maintenance crews
Decommissioning

A special annex to the contract should detail the commercial terms of the contract. The main components of the Annex are listed in Table 7.

TABLE 7. COMERCIAL TERMS

Total price of the supply
taxes, duties and custom formalities
Currency for payments

TABLE 7. COMERCIAL TERMS (cont.)

Terms of payment — Letter of credit — Advance payments — Payment instalments linked to milestones/WBS packages — Performance payments linked to measured performance criteria — Contingency fund to guard against deficiency in any of the WBS packages — Delay of payments — Banking expenses and delay in the opening of a letter of credit
Escalation calculations
Delivery terms and partial deliveries
Inspection and holding points
Claims and damages
Preliminary and final acceptance
Contract variations and payments
Guarantees
Warrantees
Penalties
Insurance
Liabilities
Dispositions — Entering into force — Modifications of the contract — Technical and administrative communications — Confidentiality — Parties' obligations — Non-validity of previous agreements — Delivery timetable — Addresses and signatures
Disputes and arbitration

2.5. PROJECT TERMS OF REFERENCE

The terms of reference may be contained in one or more documents that provide descriptions and definitions of the project. The terms of reference contain the following:

(a) The background and objectives of the project;
(b) The scope of work;
(c) The project schedule;
(d) The deliverables;
(e) The major responsibilities;
(f) The reporting obligations;
(g) The performance and compliance expectations;
(h) The resources;
(i) The contract and financial arrangements (these may only be available to selected personnel or officials);
(j) The facilities and services to be provided by the operating or owner organization;
(k) The expectations concerning technology transfer during the project.

Further details are provided below.

2.5.1. Background and objectives

A clear summarized description of the background to the research reactor project and the objectives of the project should be given. The overall objective of the project should be the delivery of a safe, secure, appropriately safeguarded and functional research reactor that can operate within the specifications detailed in the contract.

The specifications used for the bid, the terms and conditions for the contract and references to both the specifications and the contract should be summarized. There should be sufficient information in this section to inform and provide guidance regarding the execution of the project. Details of the bid should be located in the bid proposal, bid specifications and bid evaluation documentation, while details of the contract should be located in the contract documentation. As a minimum, the terms of reference should contain the contract title, the names of the contracting parties, the major deliverables specified in the contract and any special instructions that have a major effect on the project, such as special regulatory conditions, special procurement instructions.

2.5.2. Project scope

This section should define what is being procured and the methods by which that procurement will be achieved. Additionally, the project structure should be defined, including the roles and responsibilities of key personnel and the method by which the project will be managed. Different techniques are used in complex projects for managing work. One that is used often in the construction of research reactor facilities is to place the total works in defined work packages and to manage each package with an item or items to be delivered as the goal of the work package. The project WBS is defined and the individual WBS packages are linked to form the total work. The pricing of each WBS package assists with effective management of the schedule and costs of the project.

The details of the items to be included in the procurement may be listed in the project terms of reference but are more likely to be referenced explicitly in the contract and detailed in documentation that is developed under the control of the integrated management system or quality system used by the project. It can be useful to document the major items that will comprise the structures, systems and components (SSCs) of the future operating reactor facility in the terms of reference.

There will be components of the scope of supply that are specific to the research reactor and its intended uses (e.g. radioisotope production items versus neutron beam instruments for a radioisotope production reactor versus a neutron beam research reactor) and other items that are required for any research reactor. Depending on the terms of the contract, general items may include construction of all the buildings associated with the facility, technical drawings and documents for all civil works and structures, manufacture and provision of SSCs related to reactor operation, safety and security, technical documentation for SSCs and reactor operation, associated drawings for SSCs, supply of associated equipment and services needed for the completion of the project, standards and quality system requirements, technology transfer and training of operating organization personnel, computer codes and specific resources for commissioning and early operation.

Some contracts may specify supply of nuclear fuel, and if so, this should be mentioned in the project terms of reference, including supply chain issues (e.g. source of uranium or other fissionable material).

2.5.3. Project schedule

The schedule should show a timeline with major milestones and expected deliverables during the periods between the milestones. In depth schedules associated with individual WBS packages may be developed and shown in the terms of reference, but it is more likely that an overarching whole project schedule would suffice, as the schedule in a complex project will invariably change as the project progresses.

2.5.4. Major responsibilities

Section 2.2 details the responsibilities of the project manager, and one of the early and major responsibilities of the role is to define the structure and make-up of the project team. There are many different ways to allocate responsibilities, and the method chosen will be influenced by a number of factors, including the contract type and terms, availability of skilled personnel and regulatory factors. At the least, the project team should comprise a project manager, a technical manager (for reactor design and reactor systems), a contract and finance expert, a construction expert and an administrative assistant. Other personnel and resources need to be appointed on an as needed basis and, depending on the contract, this may mean few or many people being employed on the project. For example, a turnkey contract may mean a small project team with many technical experts being supplied by the contractor, whereas, in a multiple package contract, personnel from the owner or operating organization or contractors may be appointed to the project to perform the necessary activities. One specialist activity that is important for research reactor projects is the safety and licensing function, which may be located within the project or may be located outside the project, and which interacts between the project, the operating organization and the regulatory body.

The management of the construction site, including applicable regulations, licences, codes and standards, as well as responsibility and control of the site should be defined in the terms of reference.

2.5.5. Performance, compliance and reporting

The terms of reference document should specify the criteria for performance of the project, the measurement indicators applied to each criterion and the targets associated with the major deliverables. The contract specification should link these factors to the pricing and payment structure. Project performance will largely be associated with delivery of the specified items on time, within budget and at the specified level of quality. In practice, this needs to be repeated for all WBS packages within the project.

Compliance during the project is important, as the regulatory obligations that need to be met are extensive, including those concerning the environment, workplace health and safety, and possibly finance. Further, certain nuclear safety and nuclear security obligations may need to be met during the construction period, and these will be dependent on the regulations of the Member State and the licence conditions imposed for construction.

Reporting requirements, including which reports are required for which stakeholders, the frequencies of each report and the responsible person or function for each report, should be specified in the terms of reference.

Finally, the terms of reference should specify the activities and tasks to be undertaken and delivered by the project and those to be delivered by the contractor. Many of the elements of the terms of reference of the project discussed above will require the project manager and the contractor to communicate and agree on each of them. It is very important that the relationship between the principal and the contractor is managed effectively by the project manager. While this 'soft skill' is not usually specified in project documentation, it remains one of the key functions of a skilled project manager.

2.6. DESIGN AND LICENSING

It is important for design and licensing to be considered explicitly during the construction preparation period, as proper planning and execution of activities and tasks during this period will be crucial for supporting compliance with licences for the construction, future operation and security of the facility. It is important that the design be such that the constructed facility complies with the issued licences, which in turn are based upon the regulations and laws applied in the Member State. The principal mechanism that links design and licensing during Phase 3 is the execution of the design and engineering process.

As mentioned in Section 2.2, the project manager plays a central role in controlling the project, and some of the associated responsibilities encompass the execution of the design and engineering process and the links that process has to construction of the SSCs and the whole facility.

During facility construction, it is important for the main safety and security functions for the research reactor facility, which should be addressed by the design, to be considered explicitly during all stages of the design and engineering process. The main safety and security functions include, but are not limited to, requiring the following during all normal and anticipated abnormal conditions:

(a) Core reactivity is controlled;
(b) The reactor core and stored fuel assemblies are adequately cooled and secured;
(c) Radioactivity is controlled, contained or confined;

(d) Radiation doses to workers and other personnel at the research reactor facility and to members of the public do not exceed established dose limits, and are kept as low as reasonably achievable;
(e) All safety functions can be performed with the necessary reliability and the research reactor can be operated safely within the operational limits and conditions for its entire lifetime;
(f) The constructed facility is properly secured and protected once the nuclear fuel is introduced into the facility.

The design of the reactor should be flexible enough to allow the addition of test facilities that were not envisaged during the early stages of the project. These test facilities could include, but not be limited to, pressure test loops or capsules for material or fuel testing. For such purposes, the rooms for the future expected components, passages for extra cables and wiring, as well as other configurations, should be provided within the detailed design phase. Moreover, the necessary control panels should have a place in the control room.

Additionally, the design should be such that the reactor can be decommissioned safely and that impacts on the environment are minimized. The concept of defence in depth, adherence to relevant codes and standards, and construction and manufacturing of SSCs that will support a safe, secure and well operated facility are all elements of the design process that should be incorporated into this period of the project. Reference [5], which deals with the safety of research reactors, sets out the requirements for licensing and the interaction these have with design. A summary of the elements and requirements for design and licensing as described in Ref. [5] follows.

2.6.1. Authorization process and licensing schemes

The authorization process for a research reactor facility may vary among States, but spans many years, from site evaluation until after decommissioning. In accordance with IAEA Safety Standards SSR-3 [5], the major stages should include the following:

(a) Site evaluation;
(b) Design;
(c) Construction;
(d) Commissioning;
(e) Operation, including utilization and modification;
(f) Decommissioning;
(g) Release from regulatory control.

It is known that licensing schemes vary among Member States, and therefore the details of some of the activities and tasks undertaken during the construction period may also vary. At the higher level, the main concerns of any Member State during the construction preparation period will be the design and construction authorizations. The documentary requirement associated with these authorizations is the safety analysis report (SAR), which during this period may be referred to as the preliminary SAR.

Irrespective of the licensing scheme used in Member States, it is incumbent on the project manager to aim for consistency between the agreed licensing scheme and the activities and tasks undertaken throughout the whole project.

2.6.2. Safety analysis report and safety assessment

The operating organization is responsible for preparing the safety analysis report, which should provide a justification for the site, the design and the basis for the safe operation of the research reactor. The safety analysis report provides a descriptive and documentary link between the design and safety of the reactor and should be detailed enough to permit review by the regulatory body for issuing licenses. The contents of the safety analysis report should contain a detailed description of the reactor site, the reactor facility and experimental devices, and should include all other facilities and activities with safety significance. It should detail the general safety principles and criteria applied to the design for the safety of the reactor as well as the design features that provide protection for operating personnel and the public and those that provide protection for the environment. It should also contain analyses of the potential hazards from the operation of the reactor, including detailed safety analyses of accident sequences and the safety features incorporated into the design to avoid or minimize the likelihood of occurrence of accidents, or to mitigate their consequences in accordance with the defence in depth concept. Emergency arrangements should be also described.

The safety analysis report is typically reviewed and assessed by the regulatory body before construction commences, and the fundamental design needs to be largely established and documented. Because the safety analyses form the basis for the operational limits and conditions for the reactor, there is a direct link between design, safety, operation and licensing. The adequacy of the design of the research reactor should be verified by means of comprehensive deterministic safety analysis and complementary probabilistic analysis, as appropriate, and should be validated through verification by individuals or groups who are independent from those who originally performed the design work. Further details are provided in Ref. [5].

3. CONSTRUCTION PERIOD

3.1. INTRODUCTION

The construction period commences at the first pour of concrete and concludes when the research reactor facility is ready for integrated systems testing. This period entails the greatest capital expenditure during the project. The project manager continues to lead the project during this period, and, while planning remains an important element in the daily functioning of the project team and all contractors, executing the project plan comes into prominence. The plan–do–check methodology may be used to help manage the WBS packages during the construction period. It is recommended that risk management techniques be applied and used during the construction period to review progress, anticipate risks and take controlled action to reduce risk and maximize opportunities.

3.2. PLAN

The responsibility for construction activities resides with the contractor and subsidiary contractors (or partners). The type of contract will be a determinant on the detailed make-up and structure of the contractor organizations. The principal's project team is responsible for interacting with the contractor and its team so that construction is executed according to plan. The following elements for construction activities should be detailed and documented:

(a) Description of procurement, manufacturing, construction, installation and testing activities;
(b) Sequencing and linking of activities and tasks;
(c) Interfacing between tasks or disciplines;
(d) Resource allocation and planning.

3.2.1. Organization of project management

The management system should have five pillars:

(a) A general policy, to give meaning, setting goals and action plans;
(b) An organization with the resources to distribute the activities, tasks and responsibilities, and implement the management system;
(c) Processes to master the activities, their interfaces and their effectiveness;

(d) Documentation to define, guide and record the operation of processes undertaken in the project;
(e) Tools and methods (reviews, audits, dashboards, meetings) to empower the people using the management system from factual data to implementation and to draw lessons for improvement.

The leading role in project management should be in the hands of the principal, which has overall responsibility for the project in all phases and usually assumes ownership and operation of the research reactor facility.

The principal's project management functions will vary depending on the type of contract. The project team assembled in the construction preparation period may be modified and developed during the construction period to satisfy the execution of activities that are undertaken in the period. The details of the WBS packages and the timelines associated with those packages are important elements for planning the distribution of responsibilities and resources. Details of important project team personnel required during the period are provided in Section 3.2.5.

The principal's project management functions will also vary depending on the type of contract. To address the complexity of a research reactor project and to ensure the maximum effectiveness of the project management team during project execution, the principal and contractor should organize and appoint experienced project management organizations, with the intention that the two organizations will collaborate closely. This will allow integration of the knowledge, skills and goals of the principal and contractor, bringing maximum added value to the research reactor project.

Examples are provided below for typical organizational structures that may be used. In the case of turnkey contracts with the main responsibility delegated to the main contractor, Fig. 3 shows a typical organizational structure for the project management team of the principal, while Fig. 4 shows the corresponding structure for the project management team of the main contractor.

Details of the overall project organizations for principal and contractor should be established, documented and distributed to all stakeholders, clearly indicating the key people and responsibilities in the organizations. Principal contact points and all senior staff members who have project responsibility (e.g. the licensing or QA manager) should also be made known. Organizational charts showing the hierarchy within the project and in partner organizations should be added as soon as they are established.

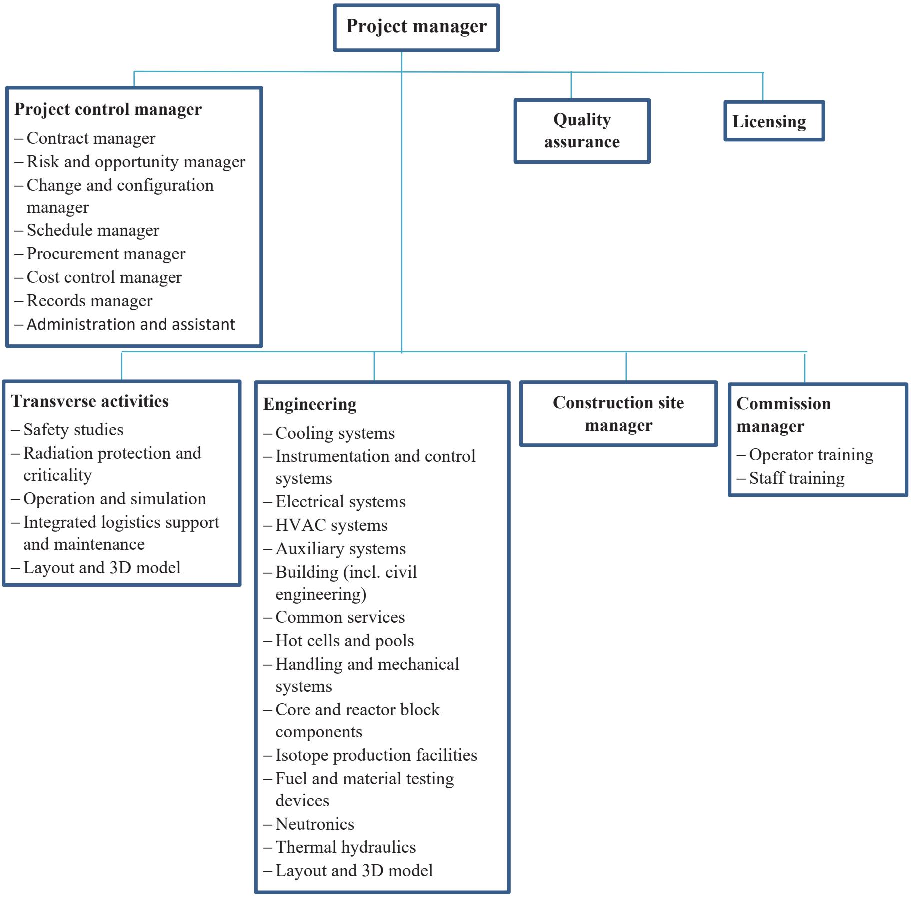

FIG. 3. Example of an organizational structure for the project management team of the principal.

The principal's and contractor's management regularly monitors the management system through the following main reviews and committees:

(a) Executive committee;
(b) Management system performance review;
(c) Steering committee for projects and offers;
(d) Project safety committee;
(e) Project technical reviews (e.g. gate reviews).

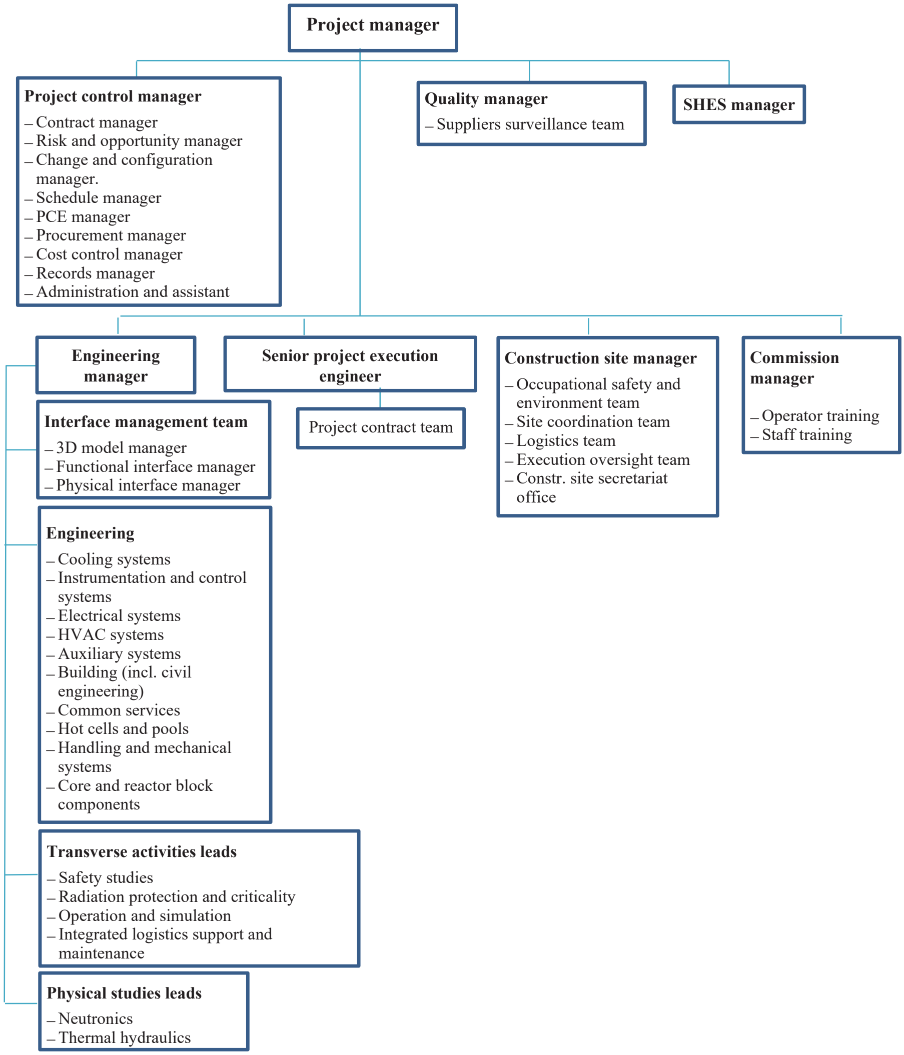

FIG. 4. Example of an organizational structure for the project management team of the main contractor.

As described in Section 3.2.1, the project manager has overall responsibility to execute the contract within the quality, safety, schedule and budget constraints that are specified in the contract.

During the construction period, the main functions of the project manager include:

(a) Having overall responsibility for the execution of the project up to the final acceptance;
(b) Developing and managing relationships with the operating organization, regulatory authorities, contractor and other stakeholders;
(c) Developing and implementing the detailed project execution strategy;
(d) Ensuring that risks and opportunities are identified and controlled;
(e) Overviewing the schedule and reviewing and modifying the project management plan if required;
(f) Assuming overall responsibility for the quality, environmental and health and safety issues of the project;
(g) Reporting of overall project progress with clear identification of key issues that affect or may influence the success of the project;
(h) Managing project closure and facility handover at the completion of the construction period.

The organization should expand during the construction phase to include:

(a) Contract manager;
(b) Project control manager;
(c) Licensing manager;
(d) Quality manager;
(e) Safety, health and environment manager;
(f) Engineering or design manager;
(g) System or work package leaders;
(h) Construction site manager.

3.2.2. Organization of project team functions

The following elements should be considered and incorporated into the organization of the project team's functions:

(a) Safety (including culture), health and environmental management;
(b) Confirmation of the master schedule for the project and implement actions to control the schedule as work progresses;
(c) Quality management (including the treatment of non-conformities, delays, deviations and regulatory interventions);
(d) Cost management;
(e) Contract management;

(f) Consultants of consultancy group to enable in depth analysis of complex projects (this may be summarized as the ‘intelligent client’ concept);
(g) Configuration management, including documentation management and control of and interaction with quality systems;
(h) Deviation management during construction;
(i) Risk management in planning, including the identification of potential risks and treatment for those risks;
(j) Contingency planning;
(k) Mobilization of human resources (operating organization and vendor resources deployed on-site);
(l) Communication (internal, external, stakeholders);
(m) Communication with the regulatory body (planning and detail is important);
(n) WBS methodology and application, including lower level methods such as product breakdown structure, cost breakdown structure and others;
(o) Procurement process (may be done in different ways depending on the type of contract);
(p) Waste management during construction and planning for waste management during future operations.

3.2.3. Construction schedule

An example of major activities that comprise the construction period are shown in Fig. 5. The labels of the major activities may be changed to reflect the content of the major activity. The details of the minor activities and tasks within each of the major activities and the sequencing of the major activities may differ depending on the type of the contract. In all cases, the project management team should monitor the progress made in each of the WBS components, bearing in mind:

— Interfaces between each of the construction stages;
— Critical timing of unexpected design modifications;
— Overall project budget.

3.2.4. Project team development during construction

Many of the key positions involved during the construction preparation period are expected to continue during the construction period, although responsibilities and tasks for some personnel may change from one period to the next. The project team should have the culture and structural flexibility to be able to support changes to the team, such as the introduction of new positions

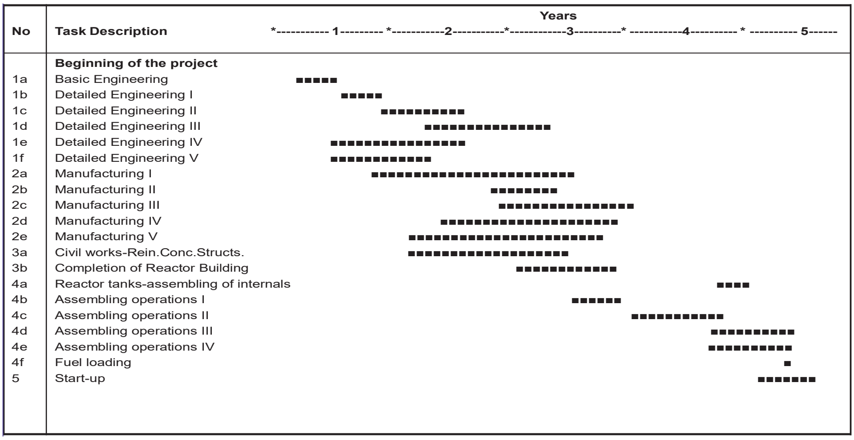

FIG. 5. An example of major activities and the time order for the construction period.

and people, and when personnel may leave the project. The ability to transition smoothly from one phase to the next will assist in making the project successful.

Turnover of workers is also an issue to be considered during the construction period. Most construction jobs are non-permanent in nature, and skilled people are required in different numbers at various times during the project. There could be various reasons for high turnover, and, assuming the incumbents are performing satisfactorily, generally attempting to minimize turnover should assist in meeting quality and safety requirements.

3.2.5. Communication

The project manager will be required to communicate with a variety of stakeholders during the project, and it is therefore recommended that efficient communication protocols and systems be established and agreed to by the operating organization or owner and, for some elements, potentially by the Member State's government. As the project grows in complexity and volume of activities, communications may need to be expanded and may become more detailed and difficult. A lack of well established communication procedures can cause substantial logistics problems, resulting in project delays. It is recommended that regular progress meetings with each partner organization and among project partners should be established early in the project. The project communications tools should include the processes required to ensure timely and appropriate generation, collection, distribution, storage, retrieval and ultimate disposition of project information that is approved for dissemination.

The basic processes to be developed are the following:

(a) Identification of the direct and indirect stakeholders — identifying all people or organizations affected by the project and documenting relevant information regarding their interests, involvement and impact on the success of the project.
(b) Development of a communication plan — defining the information that the project stakeholders need and developing a communication strategy.
(c) Distribution of information — making relevant information available to project stakeholders.
(d) Management of the flow of information — communicating and working with the stakeholders to meet their needs and address issues as they occur.
(e) Performance reporting — collecting and distributing performance information, including status reports, progress measurements and forecasts.

3.3. EXECUTION — OPERATING ORGANIZATION'S RESPONSIBILITIES

Consistent with Requirement 2 in IAEA Safety Standards Series No. SSR-3, Safety of Research Reactors [5], the operating organization should have prime responsibility for safety during the construction period. In many cases, the operating organization will delegate responsibility for many construction activities to other entities, including the main contractor and its subcontractors. While those organizations also share in the responsibilities for safety and quality, the prime responsibility should reside with the operating organization or principal. Similarly, the operating organization should ensure that quality and security issues are monitored and meet the requirements expected by regulators and as specified in the contract.

In terms of execution by the operating organization during the construction period, it should ensure that it:

(a) Has a functioning management system that has been updated for construction and integrates quality, safety, security, occupational health, environment protection and performance in a complete framework, with operation plans containing written requirements (including licensing requirements) included in clearly defined and auditable specific procedures;
(b) Appropriately trains personnel on use of the management system;
(c) Allows independent assessments and self-assessments of the management system to be conducted, so that its effectiveness can be monitored, and opportunities for improvement to be identified;

(d) Confirms with all stakeholders that the project manager has the responsibility to ensure that the project has its safety, quality and security requirements delivered;
(e) Develops a detailed construction schedule for all SSCs, which specifies witness and hold points, and documents and communicates the responsibilities for approvals at the hold points.

The activities undertaken by the operating organization during the construction period should include the following:

(a) Implementing regular interaction with the regulatory body to follow up the licensing process and facilitate inspection activities;
(b) Applying project management procedures and practices that measure project progress, verify and adjust costs, control scope and evaluate performance, including auditing of the management system of contractors, and a system for capturing and documenting non-conformances;
(c) Integrating procurement, construction and installation activities (when it is not a turnkey contract);
(d) Instituting risk management practices as the basis for taking strategic and operational decisions;
(e) Implementing a maintenance programme for stored and installed equipment;
(f) Monitoring the project team in order to ensure the availability of the needed resources for each planned activity;
(g) Developing a plan for the recruitment, training, qualification and authorization of operating personnel [11];
(h) Developing a plan on stakeholder involvement, considering at least the public, users and government.

3.4. CHECK

Prior to commencing construction, the project team should produce documentation, such as a quality control plan that encompasses all the various activities covering the design, procurement, fabrication, installation, testing and Stage A commissioning. The documentation should specify the responsibilities of the various personnel in the project organization during the execution of the project and should include how documentation is managed and the technical or managerial qualifications required for the positions in the project organization.

The project manager should monitor and review the functioning of the project team at every stage of the project.

3.4.1. Construction acceptance practices

It is the responsibility of the quality manager (or equivalent personnel) to ensure that all the construction activities are being undertaken per the required quality levels and standards. The contractor may be responsible for the preparation of a quality assurance plan (QAP) for detailed tasks such as equipment erection, structural fabrication, piping, etc., and where the hold points for inspection at various stages of fabrication or erection are indicated. The quality manager (or equivalent personnel) is responsible for reviewing the QAP prior to the commencement of construction and ensuring that the provisions of the document are adhered to. The QAP for a fabrication or erection job typically includes the following:

(a) Industrial codes and standards — the agreed and appropriate ones to be used.
(b) Material auditing — the various tests that are required to be performed on the material (e.g. chemical, mechanical, ultrasonic testing, intergranular corrosion, etc.), along with their acceptance standards. It is required that material test certificates be included in the final documentation. The quality team is also required to ensure that the specified material is used during construction.
(c) Auditing fabrication process — specification of the process to be employed for fabrication, including the quality of the material to be used, such as welding rods, gas, grinding wheels, etc.
(d) Surveillance of the erection process — how the equipment is to be erected. It is required that this be carried out per the established procedure and no unnecessary loads are to be imparted on the equipment during its installation. The positional accuracy, level and perpendicularity of the equipment are some of the details that are required to be checked.
(e) Inspection of selected manufacturing processes and manufactured items — specification of the testing required to be carried out at various stages of fabrication. The specified tests should be checked and verified by the QA team, and it is required that this be documented.

3.4.2. Preparing systems for commissioning

After the fabrication and erection of a system are completed as per the approved QAP, all of the documents pertaining to the fabrication of a system should be assembled, checked and reviewed before proceeding to the next stage, which is to make the system ready for commissioning. This is a critical stage of the project, and the project manager should establish a team (referred to as the completion task force in Section 5 of this publication) that will be the link between the construction and commissioning teams. The task force has a number of responsibilities, including verifying all the assembled documents for the fabrication and erection process and carrying out the activities to prepare systems for commissioning as well as potentially taking part in the commissioning of the systems. The tasks may include flushing, hydrotesting and operating the pumps and motors etc. from the local control panels as well as from the main control console, verifying the process data in the data acquisition system and also checking safety interlocks. These are examples and are not exhaustive.

3.4.3. Regulatory activities

Regulatory inspection teams employed by the regulatory authority are required to inspect the installation of critical components during the execution of the project. The project team should maintain a well established communication procedure to inform the regulatory authorities regarding the readiness or completion of specific activities and also to maintain the documentation pertaining to these activities. The regulatory inspections are expected to check the appropriateness of execution of activities and tasks during construction.

3.4.4. Measuring progress

It is required that the physical and financial progress parameters be established at the beginning of the project so these parameters can be monitored and measured at any point during the execution of the project. Typically, measurement is undertaken against established and known performance and progress indicators that cover scope, schedule, cost and quality. In a research reactor project, important safety and security parameters may also be established, particularly if SSCs are categorized with safety and quality levels assigned to them.

3.4.5. Risk management follow-up

A risk management system should be established and used throughout the whole project. The use of modern risk management techniques, if executed well, can identify the probable areas where risk will occur and treatments that can be applied to avoid or reduce schedule delay and escalation of cost. The risk manager (or those responsible for risk) should carry out coordination and performance evaluation using steps such as the following [8]:

(a) Brainstorming sessions to identify risk areas with competent engineers and project management staff in each technical area;
(b) Formal declaration and definition of important risk items with the support of the department or section heads within whose scope the risk item falls;
(c) Listing, sorting and weighing of the identified risks;
(d) Further definition and cost estimates for the most imminent or important risks;
(e) Input to the project cost matrix of significant identified financial risks;
(f) Definition of action programmes for timely risk mitigation;
(g) Follow-up of actions and reassessment of risks;
(h) Periodic review of inactive risks in the list;
(i) Updating the risk list and its priorities.

Each active risk item should be matched to an action that mitigates or treats the risk. The project manager should develop contingency plans that address the identified risks and incorporate the treatments to mitigate against costs and schedule problems.

4. CONSTRUCTION COMPLETION PERIOD

4.1. BACKGROUND

Construction completion is the final period for overall construction and occurs when building actions are close to an end and preparation of the reactor for commissioning is conducted. The basic recommendations for commissioning research reactors are stated in IAEA Safety Standards Series No. NS-G-4.1, Commissioning of Research Reactors [10]. Construction completion is an intensive period that requires careful management, excellent planning and execution and clear communication with many stakeholders. The interactions between the principal or operating organization, the regulators and the contractor can be demanding and detailed. The construction completion period may be relatively short when compared with the preceding periods, or it could be lengthy if problems occur during commissioning and/or finalization of the contract takes longer than expected.

The operating organization continues to have overall responsibility for safety during this period, and the project management organizations established during the preparation period and in place during the construction period remain operative, with similar responsibilities from the construction period into the completion period. It is expedient for the operating organization to prepare the operation team of the research reactor and involve them in the work during this period.

The commissioning management arrangements should be further developed in this period, and preparations for implementation are made prior to the conclusion of the period. Different Member States may implement the transition between construction and commissioning in different ways. The method chosen for this activity should be consistent with the processes and responsibilities agreed with the Member State's regulator.

4.2. RELATIONSHIP BETWEEN PRE- AND POST-CONSTRUCTION ACTIVITIES

4.2.1. Link with construction period activities

There will still be construction activities to be performed in this period. In the main these are the following:

(a) Finalizing installation and construction activities;
(b) Facility cleaning and final preparations for turning the construction site into a site suitable for operations;
(c) Testing, verification and validation of both individual SSCs and system integration tests;
(d) Preparation of as-built design documentation, which includes the results of tests and updates and modifications as required according to the test results;
(e) Development of preliminary operating manuals, surveillance and test procedures, and emergency procedures.

To define a limit between the two phases, examples of two lists of works are provided; the first are items completed during the construction period, and the second are those yet to be undertaken in the construction completion period. These examples, while typical, may not be exhaustive and may be variable depending on the project.

Works completed during the construction period include the following:

(a) Civil works and light work (including painting, installation of doors, locks, and leaktight coatings);
(b) Closing of civil work openings that were used to bring large components into the building (e.g. polar cranes, primary pump heat exchangers, vessels);
(c) Roads and underground networks;
(d) Hot cells (including liners);
(e) Pool liners (reactor and storage);
(f) Handling equipment (main and secondary);
(g) Fluid networks (heating, ventilation and air conditioning (HVAC), power, signal circuits, water, gas);
(h) Reactor block and related systems (primary, secondary, tertiary), including primary pumps and heat exchangers;
(i) Electrical power supply;
(j) Laboratory equipment, glove boxes and hot cells;
(k) Pool equipment (racks, handling rods, etc.);
(l) Cleanup of rooms.

Works that remain to be carried out during the completion period include the following:

(a) Paint touch-ups following end of assembly/test operations or minor modifications made to structures and equipment;
(b) Replugging of civil work openings once networks have been installed (fluids, electricity);
(c) Interconnection of systems inside the facility;
(d) Connection of fluids and facility networks with the site;
(e) Transfer of information to the main control room;
(f) Supply of demineralized water;
(g) Supply of fluids required for the commissioning tests (industrial water, gas);
(h) Cleanup of equipment;
(i) Minor works from all trades that were not completed during the construction period;
(j) Supply of critical spare parts for the commissioning stage and for the future operating stage (in terms of cost or procurement deadlines).

4.2.2. Link with commissioning stage

The link to commissioning is important because handovers for responsibility need to occur during this period, and the reactor enters the first phase where it performs as an integrated facility. It is also an important period in terms of human dynamics, as one major group ‘winds down’ (the principal’s project team) and a second major group ‘winds up’ (the commissioning team). It is worth noting that it is important to have an overlap in how these groups interact and operate. Communication and trust are both important attributes for progress and success during this period.

This publication does not identify which group has responsibility for cold commissioning activities. That is a decision for the operating organization, consistent with regulations and approvals from the nuclear regulator to which group authority is delegated. Experience shows that this has been done in different ways in some Member States. It may also vary, depending on the type of contract used.

At the end of the completion period, a whole facility Construction Acceptance Test (CAT) should be performed. This will occur without nuclear fuel in the facility.

4.3. COMPLETION PROCESSES

During the completion period, several processes are to be developed simultaneously, thus requiring careful planning as well as a clear allocation of duties. This section is focused on the identification of the human resources and tasks required to successfully progress to commissioning. These processes include:

(a) The formation of a multidisciplinary completion task force within the construction group for:
   (i) Receiving the SSCs being ‘released for testing’ by the construction group;
   (ii) Testing the individual SSCs;
   (iii) Integrating the SSCs and progressively testing in an integral manner.
(b) Performing the CAT for the facility.
(c) Maintaining and preserving the facility equipment during the completion period.
(d) Transferring the SSCs to the commissioning team.
(e) Periodically updating the information included in the operating limits and conditions and preliminary safety analysis report with the aim of shortening the time required to produce the safety analysis report as soon as the commissioning tests results are available.
(f) Producing the operating limits and conditions and ensuring that they are appropriate.

(g) Preparing the preliminary operating and maintenance manuals, procedures and instructions for systems and facilities.
(h) Implementing future commissioning arrangements; the commissioning programme should be prepared and submitted to the regulatory body.

4.3.1. Completion period project management

The principal's construction team remains in place in the construction completion period and has overall responsibility for the completion of construction and continues to make sure that safety documentation is updated, consistent with the construction activities that have been completed and those construction activities that continue in this period. Interaction with the nuclear regulatory body continues in the same way, with the licensing manager being the primary contact with the regulator.

The regulator will be undertaking activities associated with:

(a) Examination of the safety baseline updates;
(b) Inspections during construction and once factory tests and on-site tests have been completed.

During the construction period, the assembly of equipment and the supplier tests will have been mostly completed, and equipment will have been accepted. However, some issues will remain to be resolved during the completion phase. For this reason, the construction team should be able to:

(a) Oversee the final assembly of equipment and supplier tests, including any related changes.
(b) Complete any last reservations on equipment with the objective of validating remaining acceptance procedures for equipment. To do this, the construction team should use the tools for tracking reservations on on-site assembly and testing operations.

As the supplier tests should have been validated during the previous phase, the role of the construction team during the completion phase is to review, and if satisfied against established criteria, accept the different supplier test reports.

The project team may also be adjusted for the involvement of the groups required for the future commissioning stage, such as the formation of the commissioning team and the first operation team.

Therefore, efficient completion processes should ensure that the required conditions for starting the commissioning stage are established beforehand and that the personnel are knowledgeable and trained for commissioning. To do this, the project team should ensure that:

(a) A new organization (the commissioning team) is prepared and implemented for this testing period;
(b) Commissioning test procedures are prepared, reviewed and accepted;
(c) Equipment is prepared for the commissioning tests.

The operating organization of the research reactor should be involved in all the different tasks listed above. For this reason, the principal's project team should work in close collaboration with the operating organization. One possibility is to integrate people working for the operating organization into the project team if this has not already been done in earlier periods. Future operators, engineers and technicians should become involved in the on-site supplier tests as much as possible, even if this is limited to being observers, with the objective of learning how to operate the equipment.

4.3.2. Human resources for the completion period

In medium and large projects, assembling a completion task force to undertake the major activities and tasks during this period is recommended, and it should be formed well in advance of the activities being performed. Even in small projects, the identification of a few employees to carry out the processes below is desirable.

4.3.2.1. Composition of the completion task force

This completion task force, sometimes called the completion team or completion group, is mainly composed of members of the construction group, who should have in depth knowledge of the following:

(a) Operation and maintenance requirements of the as-built SSCs;
(b) All discipline areas, such as electrical, instrumentation and control, mechanical and hydraulics;
(c) Future operation and maintenance procedures and instructions;
(d) Future radiation protection arrangements, such as zoning, circulation and clothing arrangements;
(e) Future security procedures for operating staff, users and visitors.

Knowledge of the detailed security arrangements are restricted on a 'need to know' basis. Therefore, the only security based information required for a member of the completion task force is related to restrictions to be enforced in the future, such as:

- — Rooms with restricted access due to security reasons;
- — Emergency exits to be closed and alarmed during normal operation;
- — Access control points and log in requirements.

The importance of the completion task force during this period is demonstrated in Fig. 6, which shows the central relationship the task force has with other important groups or teams that are required throughout the project. An important consideration for all the groups is that the turnover of the facility from construction to commissioning and operation is well executed.

The major activities that the completion task force will be involved with are the following:

- — Reviewing the results of the individual system tests and proposing adjustments and modifications if needed;
- — Testing the suitability of the future operation procedures and instructions;
- — Handling deviations from design or contractual performance;
- — Coordination and performance of the facility CAT.

In addition, as some pieces of equipment are still under the responsibility of the contractor (from the commercial viewpoint) it should be recognized that the contractor's construction group employees are in charge of operating, servicing and maintaining that equipment. Therefore, interaction and communication between all the groups is important.

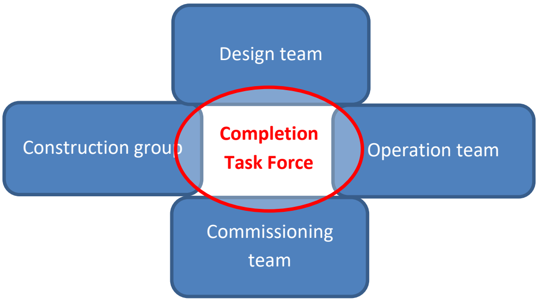

FIG. 6. Relationship between completion task force and other groups in the construction completion period.

4.3.2.2. Completion task force responsibilities

Overall responsibility for safety remains with the operating organization, and protection of site construction workers with the contractor as per the occupational health, safety and environment requirements in place at the construction site. The completion task force is a functional group, and therefore the responsibilities of the task force are purely operational.

4.3.3. Releasing of SSCs for testing

During the completion period, the installation of the SSCs is finalized and the completion task force should verify that they are ready to be tested. A release for testing certificate should be prepared for each SSC that is being finalized by the construction group, ensuring that:

(a) The SSC is clean, purged and filled with working fluids, if applicable.
(b) The temporary bypasses, filters and strainers, resistors, blind flanges and other elements that should be removed before routine operation are clearly marked (a comprehensive list should be available).
(c) All the labels and tags are properly installed, with clear identification of the:
  (i) Components;
  (ii) Commands, regulators, switches and indicators;
  (iii) Type and flow direction of the transported fluids;
  (iv) Warning and precautions labels (visible and correct).
(d) Protective circuits have been tested and are operative.
(e) Electrical and grounding connections have been tested.
(f) The SSC instrumentation is operative and has been properly calibrated.
(g) Operation keys are under adequate control (ensuring that the SSC will only be operated by authorized persons).

The completion task force receives each SSC with an approved release for testing certificate and associated documents, such as:

(a) Operating and maintenance procedures and instructions.
(b) An installation ‘punch list’ containing some observations or deviations that should be properly addressed in future stages.
(c) An SSC history docket, including:
  (i) Vendor documentation (manuals, instructions, warranties, etc.);
  (ii) Installation documentation.

The SSC operation keys (including main switchboards and motor control centres) are also transferred to the completion task force, which will be responsible for operating, maintaining and servicing the SSC during the testing phase.

4.3.4. SSC testing

Testing of individual SSCs may proceed after the respective SSC release for testing certificates issued and the completion task force considers the conditions appropriate for testing, as per the pre-commissioning testing plan agreed between the contractor and principal:

(a) The supporting systems have been tested and are operative.
(b) The required resources are available, including:
    (i) Human resources to operate the SSC;
    (ii) Testing equipment has been installed and is operative.

During testing, the proper operation of the system is ensured, in consideration of the particular set-up. In some cases, working conditions during operation are simulated by adequate temporary arrangements such as orifice plates for simulating pressure drops or resistor banks for simulating power consumptions.

In general, the sequence of individual tests starts with those SSCs that support other systems such as the electrical or compressed air systems, but it is also advisable to test warning and emergency systems, such as the fire detection system and the emergency lighting system.

In a similar way, the facility's supporting infrastructure should be made available for this testing period, including first aid facilities distributed in the reactor building and workshops.

The availability of the main control room as the place centralizing the daily activities should be considered, although it should be recognized that many construction activities may be ongoing in this room, and therefore care should be exercised when undertaking tests.

The documentation produced during this testing phase should be incorporated into the history docket or a similar recording document or system.

The list of the temporary bypasses, filters and strainers, resistors, blind flanges and other elements that should be removed before routine operation, which is available at the time of the release for testing certificate, needs to be documented properly.

As individual tests of SSCs progress, some integration tests may be initiated for testing interfaces. These integration tests will require larger loads on the electrical system, allowing it to be evaluated in conditions that are closer to the nominal ones.

Integration of the centralized control and monitoring systems may also be implemented progressively, in some cases as part of the individual SSC test or as part of the control and monitoring system testing.

4.3.4.1. Testing of core region (and reactor pool)

The mechanical components located in the core region (within the reactor pool for pool type reactors) should be tested in dry and wet conditions (obviously not for reactors without fluid in the operating core). The first set of tests allows verification of the tolerances and alignments of components, while the second, which should be performed in operation positions, allows the testing of operation tools. Mock-ups simulating fuel assemblies or experimental devices may be required to perform these tests, reducing the possibility of damage and helping to detect errors in construction and completion.

The dry test should be developed as thoroughly as possible because, once the reactor pool (for water based reactors) is filled with water, lowering the water level to repair a construction may introduce significant project delays and generates large quantities of water that cannot be recovered unless the facility has a refilling pool.

Filling the reactor pool with water constitutes a relevant milestone during the construction completion period and requires a high degree of cleanliness and tidiness in the related areas. From the water filling onward, all the works performed in the surrounding areas should be analysed and approved. Further, the clothing code for the facility should be instituted to assist with preserving pool water quality. An important prerequisite for filling the pool with water is the testing of the ventilation ducts servicing the areas connected to the pools areas to assist with ensuring pool water quality, since construction dust and particles should be eliminated.

4.3.4.2. Testing of lifting devices

Lifting devices are SSCs that are usually tested early in construction, since they are required for the installation of heavy equipment. During completion small lifting devices for particular use in the pool and core operations or experimental facilities should be tested prior to commissioning.

One important set of lifting devices to be tested are those operation tools that are to be used in the routine utilization and operation of the facility, such as:

— Lifting devices for fuel assembly underwater handling;

— Ropes and hooks for targets and experiments involving underwater handling;
— Anchoring points for temporary underwater storage of heavy items.

Those devices required for handling heavy components in the future, such as spent fuel casks, should be retested during the completion period (in addition to previous installation tests) to ensure that construction activities have not affected safety characteristics such as emergency breaking or speed and position control.

4.3.5. Construction Acceptance Test and facility release for commissioning

As the SSCs are being finalized, individually tested and integrated, the tests become progressively more complex, and a high degree of coordination is required. It should be recognized that in most cases these tests will never fully challenge the SSC, as the operating conditions, in particular under expected radiation and thermal power levels, cannot be simulated and can only be fully realized at full power. Nevertheless, it is important to test and verify support systems such as the electrical systems under full load conditions prior to releasing the facility for commissioning.

While the final integration test without the nuclear fuel loaded into the core may be performed under different conditions by different Member States, this section gives an explanation of the general arrangements required for the CAT, sometimes referred to as the site acceptance test.

4.3.5.1. Prerequisites for the Construction Acceptance Test

Prior to the CAT the completion task force should complete all the required SSC tests, and all observations or deviations should be documented and understood, with SSCs accepted or modified and retested and verified prior to approval for the CAT.

In addition, the following should be in place:

(a) All emergency management and preparedness procedures, functions and capabilities (with an exception made for radiological emergencies);
(b) SSC monitoring and control from the main control room;
(c) First operations team fully operative and mirroring the operation of the SSCs performed by the completion task force;
(d) Commissioning group available for participation in this test;
(e) Required number of people to operate the facility for the entire test, which may require the arrangement of shifts;
(f) Operating documentation, including manuals, procedures and instructions;

(g) Access control procedures, although the presence of personnel in some areas that will be restricted as classified in the future may be authorized temporarily so that the required measurements or observations may be undertaken.

4.3.5.2. Construction Acceptance Test or cold site acceptance test

To execute the CAT, the facility should be started per the operating procedures, including the following:

(a) Startup walkdown, including the valve line-up checking;
(b) Startup of components that are operated locally, with verification of working parameters such as power consumption, pressures, flows, etc.;
(c) Startup of components and systems from the main control room (complemented by field surveillance and measurements).

Operation of the reactivity control devices should be performed from the main control room (complemented by field surveillance and measurements), including the triggering of protective actions. In some cases, simulators may be installed to simulate signals such as neutron fluxes to make it possible to test some features such as automatic reactor trips.

The CAT should be performed for a sufficient amount of time for to ensure that nominal conditions are achieved. This time period should be defined before the start of the test and assessment, and corrective actions should be performed if the test fails to run for the set period.

This test is a good opportunity to evaluate operational arrangements, such as the following:

(a) Filling of the main control room log book;
(b) Shift turnover procedure;
(c) Periodic field surveillance procedures.

At the end of the CAT, all of the simulators or bypasses that have been installed should be properly removed. The commissioning team should be aware of this very important task, and it is advisable that they take ownership of these temporarily installed pieces of hardware (simulators and bypasses).

4.3.6. Operating documentation testing and finalization — as-built documentation

The operating documentation for the research reactor facility should be developed throughout the construction period, be consistent with the design and licensing conditions and use previous experience from the operating organization, the contractor and the consultants (if used). Verifying the suitability of these procedures and instructions should be undertaken in the completion period as:

(a) The documentation from the suppliers of commercial off the shelf components is available and can be merged into the procedures and instructions.
(b) Measured parameters are available, providing reference values (i.e. pressures, temperatures, power consumption, etc.) that can be incorporated into the instructions.
(c) The layout of the instruments may be modified, as may the order of the checks and walkdowns envisaged during design.
(d) The timing of the startup manoeuvres and the time for reaching nominal conditions may require modification of existing instructions, or new instructions.

Feedback from the first operations team should be considered, and modifications in the operating documentation should be introduced, if applicable.

The completion period is also the proper time to update the engineering documentation, producing the as-built version incorporating all the modifications produced during the construction period, including the following:

(a) Modifications required to accommodate interferences in the field (e.g. pipeline clashes);
(b) Changes between the hardware envisaged during design and the hardware actually procured;
(c) Final routing of small pipelines not identified in the design and engineering (e.g. fire sprinkler tubing).

It is important for documentation produced during the construction stage to be issued formally, including:

(a) A register of the embedded components (technical information, pictures, videos);
(b) Records of the materials used to manufacture relevant items;
(c) Records of the manufacturing procedures and tests;
(d) Records of the installation procedures and tests;

(e) Records of SSC release tests.

Another important activity is the collection of the information required for updating the preliminary safety analysis report in preparation for commissioning.

4.3.7. Updating facility configuration and main data

A configuration baseline for the facility should be a deliverable supplied by the contractor at the end of the design stage, and this configuration should be updated in a similar way to that described for the facility documentation discussed in Section 4.3.6.

The operating organization should ensure that data and information that will be necessary for safe and reliable operation are included in the configuration update, including the following:

- Contact details of the commercial off the shelf suppliers;
- Updated servicing requirements;
- Updated list of consumables (oil, filters, fuses, etc.);
- Accountability of the spare parts available and those that should be purchased for commissioning and future operation.

The availability of test results also allows the facility's main parameters (which in some cases are recorded as configuration items) to be updated. The values, uncertainties and measuring ranges can also now be collected, recorded, documented and incorporated where needed.

4.3.8. Gradual implementation of commissioning arrangements

The completion period should be used to gradually implement the arrangements for commissioning, which should be fully operative at the start of the commissioning. Major issues to be addressed include the following:

- Area classification and signalling (both radiological and security), including access and permanence arrangements;
- The clothing requirements for workers, users and visitors covering all areas;
- Contamination monitoring and clearance;
- Installation of personnel protective equipment (PPE);
- Paging and warning systems;
- Evacuation procedures.

The following paragraphs elaborate the gradual implementation recommendations for each case.

4.3.8.1. Area classification and signalling (both radiological and security)

Area classifications should be in place when commissioning commences and all involved personnel (operating organization, contractor, principal and others) are required to have detailed knowledge of the area classification scheme, its implementation and its requirements. Classifications and notices used during construction should be removed, and special emergency access doors and pathways used for construction should be closed and, if required, alarmed, so that the conduct of commissioning is not compromised. Emergency exits should be cleared of construction debris and ready to be used, including being clearly marked. Security arrangements should be implemented concurrently, commencing with rooms where security related equipment is installed.

Door and gate keys that were issued during construction need to be collected and stored. It may be necessary to install new locks or new combinations on locks to give assurance of proper security control of the facility premises.

Temporary guidance and signage may need to be deployed throughout the facility to assist personnel with the changed arrangements. Certain locations in the facility, such as the main control room and the reactor hall, should have sufficient and minimum number of staff authorized for entry and work activities as soon as the conditions for completion allow.

Close to the commissioning stage, total cleaning of the facility should be performed for the installation of the final finishing items, such as furniture and appliances. At this time, hard copies of technical documentation to be used during commissioning and routine operational needs to be placed in the required operations rooms.

4.3.8.2. Clothing requirements

Entry to certain areas, such as the reactor hall, may require the use of PPE, such as laboratory coats, shoe covers and gloves. The use of such garments needs to be incorporated into the radiological protection arrangements and the area classification scheme. Benches and wardrobes for storing these elements should be installed in the assigned rooms together with instructions on how to wear and dispose of or recycle them. It is advisable for the colour selected for these protective clothing to be different from any similar types of garments used for completion tasks.

4.3.8.3. Contamination monitoring and clearance

The stations and equipment for contamination checking and clearance of personnel, equipment and tools should be fully operative at the end of the completion period. Checking equipment functionality and the process for checking and clearance is advisable, including using small radioactive sources. Instructions on how to use these instruments should also be posted nearby, together with the instructions to be followed in case an alarm is triggered at the time of the measurement.

Clearance of equipment and tools when exiting areas that are classified for radiological work requires the installation of appropriate instruments and trained staff to assist when necessary. All workers that access the affected areas need to be informed of these procedures so that contamination events are avoided during commissioning.

4.3.8.4. Installation of PPE

Specialized PPE may also need to be used in other areas within the facility. Some of the other considerations are the following:

- The use of decontamination showers for non-radiological purposes should be prohibited. Decontamination equipment (soaps, brushes, etc.) should be installed in these rooms and entry limited to authorized personnel only.
- Masks and breathing apparatus should be positioned in selected locations.
- Emergency equipment such as stretchers and first aid kits should also be installed and ready to use by the end of the completion period.
- Portable radiation detectors, air samplers, temporary barriers and other emergency equipment are to be deployed in a secure room to be available at the time of the commissioning, together with the applicable procedures and instructions.

4.3.8.5. Paging and warning systems

The paging and warning systems, after installation, testing and release for utilization, should be used only for the purposes for which they were designed, such as operations, maintenance and utilization activities. Predefined messages may be scripted and used to assist with proper application of the paging system.

Warning signals should be tested and, if required, used by the end of the completion period so that personnel are able to respond to alarms appropriately when they occur. Rehearsals and tests should be scheduled and announced prior to commissioning.

4.3.8.6. Evacuation procedures

Similar to the testing of warning signals prior to commissioning, the facility evacuation procedure should also be tested prior to commissioning. The scenario used should not be overly complex and should test the suitability of the arrangements, including the following:

(a) Adequacy of muster points and evacuation routes;
(b) Appropriateness of the evacuation time achieved;
(c) Accessibility for ambulances;
(d) Accessibility for fire trucks and availability of water supply connection points;
(e) Communication equipment with local and external organizations;
(f) Availability of emergency equipment.

4.4. TURNOVER PROCESSES

Transfer of control of the facility or 'turnover' is an important part of the completion period. There are two main turnover processes:

(a) Individual system turnovers — the system and component jurisdiction are transferred from the construction group to the completion task force after the system and components being turned over have been checked and tested for installation correctness, cleanliness and completeness.
(b) General system and component turnovers — systems and components are transferred from the completion task force group to the commissioning group after the construction and other activities have been completed (as noted before there may be different ways in which to perform these activities).

The turnover package submitted to the commissioning team should include the following:

(a) Completion certificates;
(b) As-built design documentation;
(c) Process and instrumentation diagrams and piping, building and electrical drawings;
(d) Facility operation and maintenance manuals, procedures and instructions;
(e) Equipment alignment data sheets;
(f) Calibration records and certificates;
(g) List of special tools and spare parts;

(h) Test results;
(i) Equipment specification;
(j) Maintenance records and vendor drawings;
(k) Copy of outstanding non-conformance reports, field change records;
(l) Work completion certificate;
(m) Area/room check and exception list;
(n) Area/room key list;
(o) Building layout drawings.

4.5. PRESERVATION OF RECORDS

Construction records are required by the applicable codes, standards, specifications and regulations and by the operating organization. These records are assembled and retained as history dockets by:

(a) The construction group during the construction period of the project;
(b) The completion group during the completion period (if the group has been established);
(c) The commissioning group during the commissioning phase of the project;
(d) The operating organization during operation;
(e) The decommissioning organization.

Preservation of all history dockets prepared by all parties involved is ultimately the responsibility of the operating organization. Construction contractors and subcontractors prepare their history dockets and history files as per the site project management quality requirements.

For manufacturing records, it is the responsibility of the contractor to ensure that inspections, tests and examinations have been carried out in accordance with the accepted inspection and test plans and checklists.

All quality assurance procedures should contain clear requirements regarding record keeping of all contractors to ensure that:

(a) The contractors inspect the manufacturing and installation of SSCs in accordance with the applicable procedures;
(b) Applicable procedures and technical and quality requirements have been followed;
(c) The drawings, specifications, codes, standards and regulations have been followed.

Figure 7 shows typical turnover from completion to commissioning.

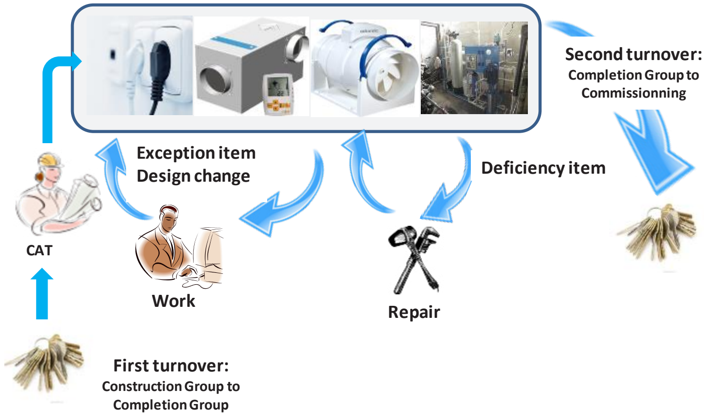

FIG. 7. Typical turnover from completion to commissioning.

The manufacturing records should include the following:

(a) Certificates showing that the inspection status was maintained, and items were properly identified;
(b) Qualification of the suppliers demonstrated through audits and quality system verifications;
(c) Demonstration that the valid versions of applicable specifications, drawings, standards and procedures were used;
(d) Demonstration that qualified personnel executed the work and that environmental and seismic qualifications are complete and acceptable;
(e) Demonstration that measuring and testing equipment was calibrated;
(f) Demonstration that data and test results were accurately recorded and evaluated;
(g) Demonstration that non-conformances were properly documented and controlled, and that equipment and materials meet all specified requirements;
(h) Demonstration that packaging and marking are correct and meet project requirements;
(i) Demonstration that equipment and materials were all duly released.

The installation records should include the following:

(a) The qualification certificates of the people installing the SSC;
(b) The installation protocols fulfilled during the installation works;
(c) The testing of the interfaces with other SSCs;
(d) The release certificate from the people installing the SSC.

The construction or completion group, if assembled, will deliver the history dockets to the commissioning group, who will be responsible for further updates, including the addition of the commissioning test results, if applicable.

4.6. ARRANGEMENTS FOR COMMISSIONING AND OPERATION

4.6.1. Generic project management structure for commissioning

Commissioning of the reactor is a vital process in its life cycle, as it includes the integration and testing of all SSCs, proving that a complete facility can be operated safely and securely. It is a time of transition and therefore carries with it risks that need to be understood and addressed. IAEA Safety Standard Series No. NS-G-4.1, Commissioning of Research Reactors, should be used to develop the commissioning programme [10]. While different projects and Member States may undertake commissioning in different ways, it is important to ensure that:

(a) Safety is the first priority for all the teams.
(b) Responsibilities for activities and tasks are understood and communicated clearly.
(c) The milestone for handover of responsibility from the construction group to the commissioning team is understood and communicated clearly.
(d) The information and knowledge gained during construction are passed from the project and construction teams to the commissioning team.
(e) Plant documentation is updated from the construction activities and reviewed and approved prior to commissioning.
(f) Commissioning is used to assist in the education and training of operating personnel, as this opportunity occurs once in the lifetime of the facility.

The project team that was in place during construction can be modified during the transition to commissioning so that the knowledge possessed by the team is utilized most usefully during commissioning. This may entail personnel transferring into new roles in the commissioning team, ad hoc committees, or the future operating organization.

Documentation management is another important aspect that needs to be transferred from the construction project team to the operating organization and the commissioning team. The relationship with licensing authorities should also be transitioned successfully during this time.

5. MAJOR MODIFICATIONS

5.1. INTRODUCTION OF MAJOR MODIFICATIONS

Modifications to existing facilities should be conducted so that the impact on the safety, security and availability of the research reactor is minimized. The modification may involve the addition of experimental facilities or activities such as the refurbishment or replacement of SSCs. A comprehensive management plan should be established before commencing work to ensure that the objectives of the planned modification are fulfilled.

IAEA Safety Standards Series No. SSG-24, Safety in the Utilization and Modification of Research Reactors [12], provides detailed guidance on the execution of projects covering new utilization activities and modifications for an existing reactor facility. This section of the publication covers a few key aspects related to the management of the modification work, which might be helpful to Member States who plan upgrades or modification to an existing research reactor.

The modification work is in general characterized by the following factors:

(a) Extent of safety implications for the existing research reactor;
(b) Extent of security implications for the existing research reactor;
(c) Duration of works requiring the reactor to be shut down;
(d) Expected dose rate from the works;
(e) Interference with the existing facility operation.

The above factors will prescribe the nature of the work. Some major modification works, such as the installation of a cold neutron source or high pressure, high temperature fuel test loop into the reactor structure or a serious change or repair to the specific structure in a high radiation environment, require a well prepared management plan and will involve substantial design and engineering effort through the whole work process.

From an overall project management perspective, there is not much difference between the processes for a modification project in an existing facility and those for a new research reactor construction project, but there are differences in execution details and responsibilities. For example:

(a) All utilization and modification projects should be subjected to a screening process to determine their implications for safety and the related safety category of the experiment or modification [12].

(b) Modification projects may involve work in areas where there are contamination and radiation hazards and therefore should be planned to deal with those hazards accordingly.
(c) The position of reactor manager is in place during modification projects and therefore the overall responsibilities that are assumed for the facility reside with that person during the conduct of the modification work.

The modification work may be divided into four stages, namely planning, implementation, licensing and operation, with particulars for each stage given below.

5.2. PLANNING

If the modification work has major implications for reactor safety, comprehensive work planning is required with the aim of analysing the consequences of the modifications in all operational states, including the effect of the modification on the reactor operating limits and conditions. IAEA Safety Standards Series No. SSG-24, Safety in the Utilization and Modification of Research Reactors [12], states that the following should be considered during the planning stage:

“— Planning and prioritization of work;
— Meeting all relevant regulatory requirements and demonstrating that the overall level of safety will not be reduced;
— Meeting the requirements derived from the operational limits and conditions;
— Evaluating the feedback of operating experience from similar utilization or modification projects;
— Addressing the maintenance requirements for the experiment or the modified system or component;
— Ensuring the availability of qualified personnel with suitable skills;
— Establishing appropriate operating procedures, including those for assessing and correcting non-conforming items;
— Performing and documenting the required inspections and tests, including those required for commissioning an experiment or modification;
— Performing and documenting the required training and instruction.”

A work schedule should be defined before the start of work on the basis of agreements with the operating organization and regulator. It is important that the nature of the modification, project milestones and licensing implications be well understood by the regulator. In some circumstances the regulator may need to approve the work prior to commencement.

The time and duration of reactor shutdown for the modification related works should be clearly indicated on the work schedule. The reactor shutdown schedule should be based on communication and interactions with user groups.

The modification work may involve interference with and disruption to existing structures involving dimensional changes, and replacement equipment with new dimensions and ratings. In cases where reactor internals change, accurate dimensional changes need to be planned, documented and tested before the end of the design is completed.

Some modification work may be undertaken in highly contaminated areas, such as the reactor core or in high radiation zones, and in such cases a special radiation protection plan and procedures should be developed. Some examples of the application of the plan during the field works may include:

(a) Special access control to facilitate movement of people and materials into and out of the work area by adopting a ‘temporary exemption of radiation zone’ with a proof of minimum spread of contamination and dose to workers.
(b) Disposal plan for radioactive waste generated from the field works. A self-disposal record should be kept as per the protocol specified in the radiation protection plan.

5.3. IMPLEMENTATION

The management activities during the implementation process are not much different from those for new research reactor construction. The implementation proceeds from design, fabrication, installation and performance testing in the same way as for new construction. The following points should be considered in the case of modifications.

5.3.1. Design

As a first step, the project manager should appoint a dedicated engineering team to analyse the impact of the modification on the existing safety case. The scope of the work for engineering, the level of licensing and the interfaces with the existing facility can be defined on the basis of the safety analysis.

The categorization of the experiment or modification should provide the basis for determining the detail and the extent of the safety analysis and the review to be performed. The safety categorization is then connected to the safety classification of the SSCs to be involved in the modification work. It is important that the safety categorization and SSC classification be based on the safety philosophy already applied to the existing reactor concept. That is, the engineering rules of the modification work should be compatible with the codes and standards applied to the existing facility in order to maintain consistency with the design bases.

5.3.2. Manufacturing

In cases where the modification is physically interconnected with critical structures such as the reactor core, an in situ, as-built dimension check is required to avoid any unexpected physical misalignment during the installation work. The measured practical dimensions should be properly reflected in the fabrication.

A mock-up test with a prototype is highly recommended to check expected performance and possible unforeseen problems. The mock-up test should be performed before starting the production unit.

5.3.3. Installation

In cases where installation of the modification would be accompanied by radiation exposure to personnel, a radiation work plan should be prepared with the objective of minimizing the dose to personnel. The development of appropriate radiation shielding and of detailed work procedures should be undertaken on the basis of results and experience gained from the mock-up tests. As part of the monitoring of the work site, regular health physics surveys should be conducted along with simultaneous monitoring and measurements as the installation proceeds.

Communication between the work site and the control room should be in place and conducted effectively for the total period in which work is undertaken at the work site.

5.3.4. Commissioning

A stepwise test concept starting with a unit or component test, proceeding to a system test and finishing with the reactor integrated test should be defined in a commissioning plan for the modification. Any tests that require the reactor to be shut down or placed into a non-standard configuration should be clearly indicated and documented in procedures. The special conditions of the tests should be properly considered in the work schedule. Any changes to existing reactor operating procedures should be checked, verified and approved with reactor management before the start of the reactor integrated tests and should be refined after the successful completion of the commissioning tests.

5.4. LICENSING

The requirements for licensing will be established during the categorization, and assessment of the modification in the case of major modifications will most likely require review and approvals by the regulator. Issues and considerations for the licensing stage may include the following:

(a) Design requirements, methodology of safety analysis and acceptance criteria;
(b) SSC classification and codes and standards to be applied;
(c) No adverse effect on the existing safety philosophy;
(d) Licensing scheme to apply to the modification work should be agreed in advance with the regulator, prior to commencement of physical work;
(e) Regulator's licensing plan incorporates the project schedule, indicating the predefined reactor shutdown made by the project team;
(f) Regulator's detailed inspection plan with the hold points available and incorporated into the schedule before physical work proceeds.

5.5. OPERATION

Involvement of reactor operating personnel in the modification works is very important because all of the activities are closely related to the existing facilities and the modification may have a large influence on the operation of the reactor. Having the knowledge of the operating group available to the project team should provide benefits to execution of the project. Direct participation of operating staff in the commissioning works is encouraged in order to facilitate the turnover of the modification to the operational state.

Configuration management is also an important element in the modification, and the modifications to existing drawings and documents should be managed under the established integrated management system with all revisions clearly described, recorded, reviewed and approved. As a final step, the revision of operating procedures and safety documents should be updated on the basis of the results of the commissioning of the modification.

6. CONCLUSIONS

This publication provides guidance to Member States on the detailed project management requirements necessary to undertake the construction of a new research reactor and for managing modification projects in existing research reactor facilities.

By following the information in this publication, project teams will be able to manage research reactor construction projects effectively, take into account the most important aspects of work and identify and predict risks and determine a strategy for overcoming them.

The key aspect of the successful implementation of the research reactor construction phase is thorough preparatory work, which includes not only the project work itself, but also the overall development of the research reactor programme and the development of nuclear infrastructure. A logical and detailed strategic plan, a well designed feasibility study and an adequate licensing system play a crucial role in the successful implementation of the project.

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Annex

EXAMPLES OF PROJECT MANAGEMENT FOR CONSTRUCTION OF OR MAJOR MODIFICATION IN RESECRCH REACTORS

Practical examples and lessons learned from project management for the construction of or major modification in research reactors are provided in the three case studies in this Annex posted online for Egypt[1], the Republic of Korea[2] and Morocco[3]. Each example follows the same format, consisting of the following details.

NAME OF COUNTRY

1. BRIEF DESCRIPTIONS (approximately three pages)
    1.1. History of research reactors in the country (approximately one or two pages)
    1.2. Project data: project title, reactor specification, project scope, project schedule, cost (approximately one page)
    1.3. Contract type: description or chart (approximately one or two pages)
    1.4. Project organization (one or two charts, depending on phases)
2. LESSONS LEARNED (two to three pages)
    2.1. Project management — construction phase
    2.2. Project management — commissioning phase
    2.3. Conclusions and recommendations for new sites or to newcomer countries

Note: Template can be modified as required on a case by case basis for the construction of research reactors or major modifications such as power upgrades, core conversions and installation of cold neutron sources.

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[1] https://nucleus.iaea.org/sites/connect/RRIHpublic/CompendiumDB/Shared%20 Documents/Egypt/

[2] https://nucleus.iaea.org/sites/connect/RRIHpublic/CompendiumDB/Shared%20 Documents/Korea/

[3] https://nucleus.iaea.org/sites/connect/RRIHpublic/CompendiumDB/Shared%20 Documents/Morocco/

ABBREVIATIONS

CAT	Construction Acceptance Test
HVAC	heating, ventilation and air conditioning
PPE	personnel protective equipment
QA	quality assurance
SAR	safety analysis report
SSCs	structure, system and components
WBS	work breakdown structure

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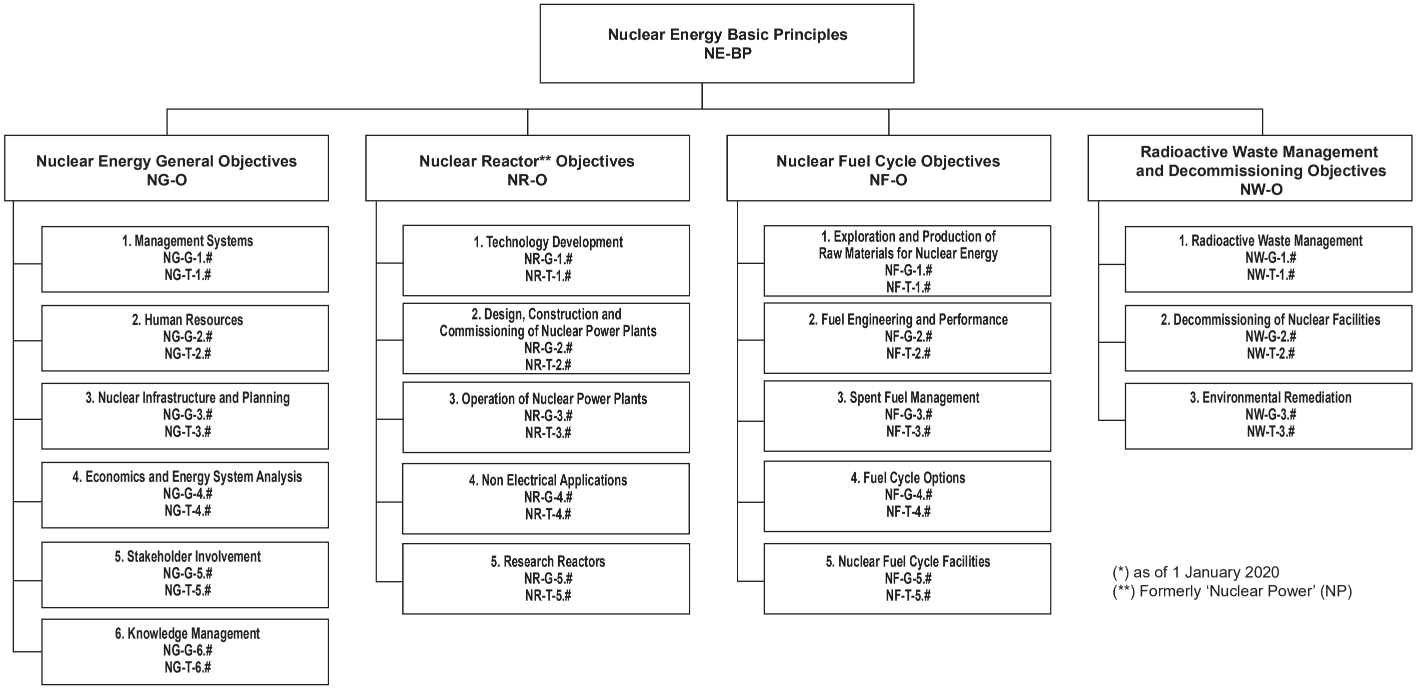

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Providing a comprehensive overview of project management for the construction of research reactors, this publication gives guidance to Member States on the best practices that will assist in the realization of that phase of a research reactor deployment project. Member States planning to embark on a research reactor programme together with a nuclear power programme may also refer to this publication to ensure that the approach and methodology for the implementation of both is harmonized, efficient and effective.

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